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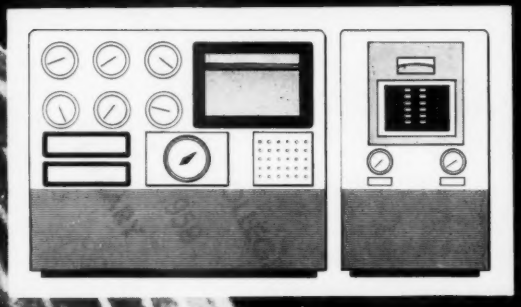

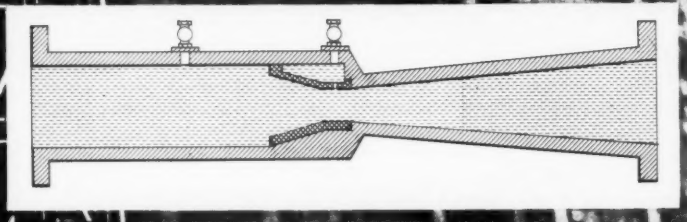

Instrumentation for the Dounreay Fast Breeder

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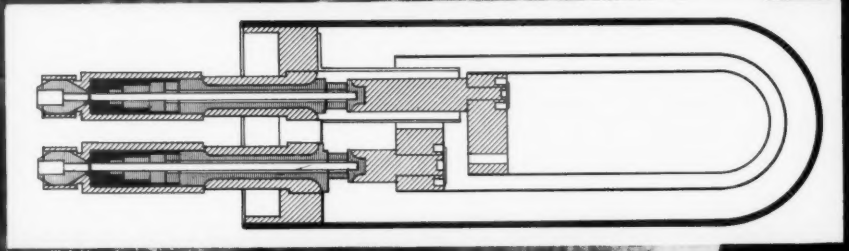

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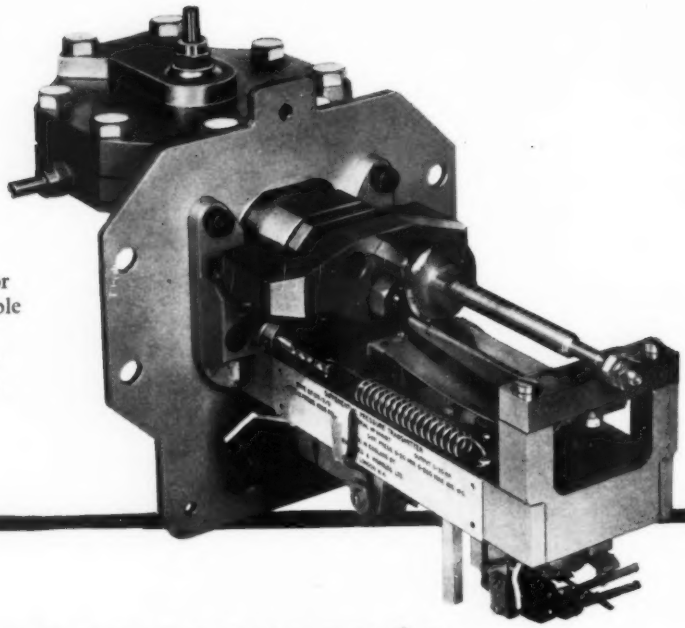

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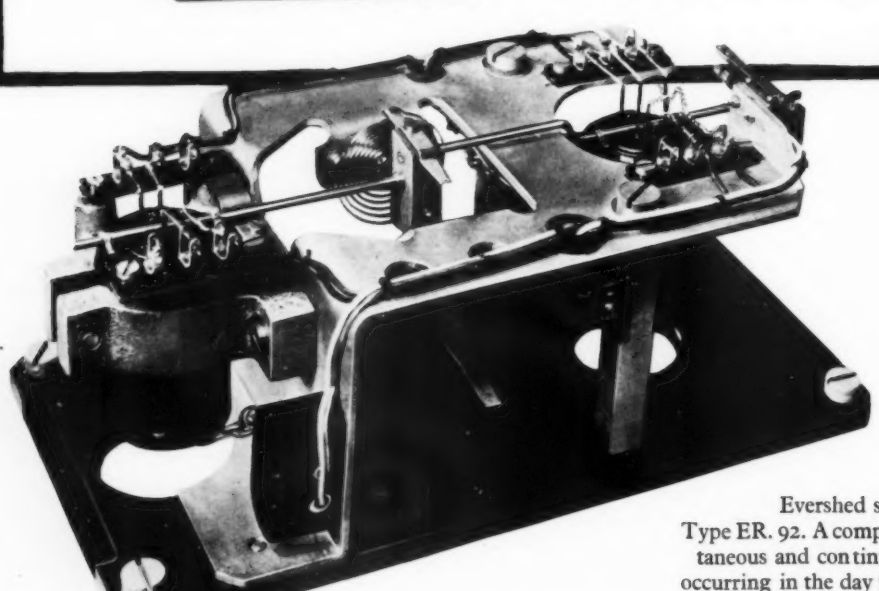

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VOL 4 NO 44 DECEMBER 1959

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Subscriptions to publishers Rowse Muir Publications Ltd. Single copies UK 3/6, 5/6 overseas, 75c US and Canada. One year's subscription UK £2.2.0, overseas £3.3.0, USA and Canada $8.00. Three years' subscription UK and overseas £5.0.0, USA and Canada $20.00.

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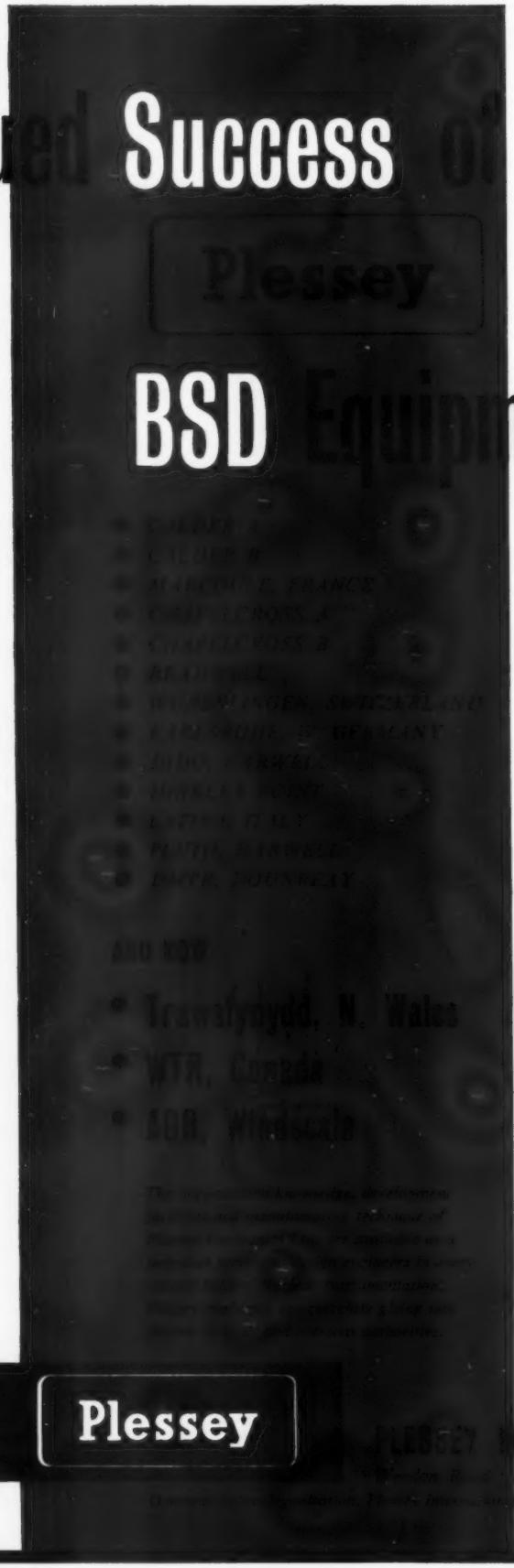

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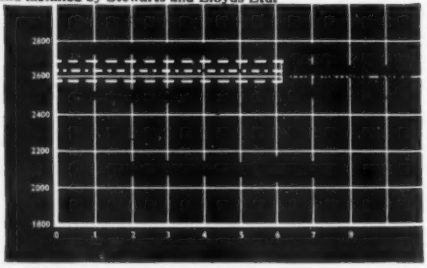

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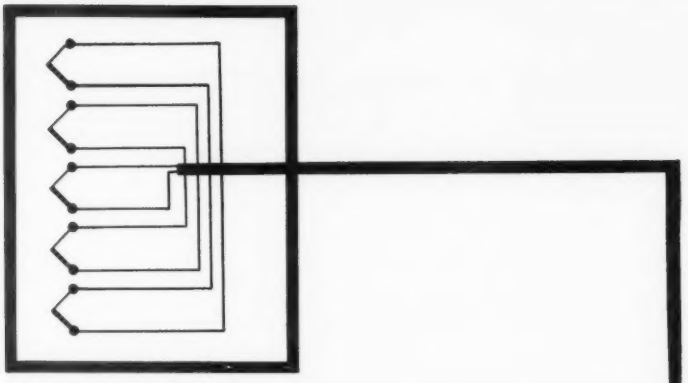

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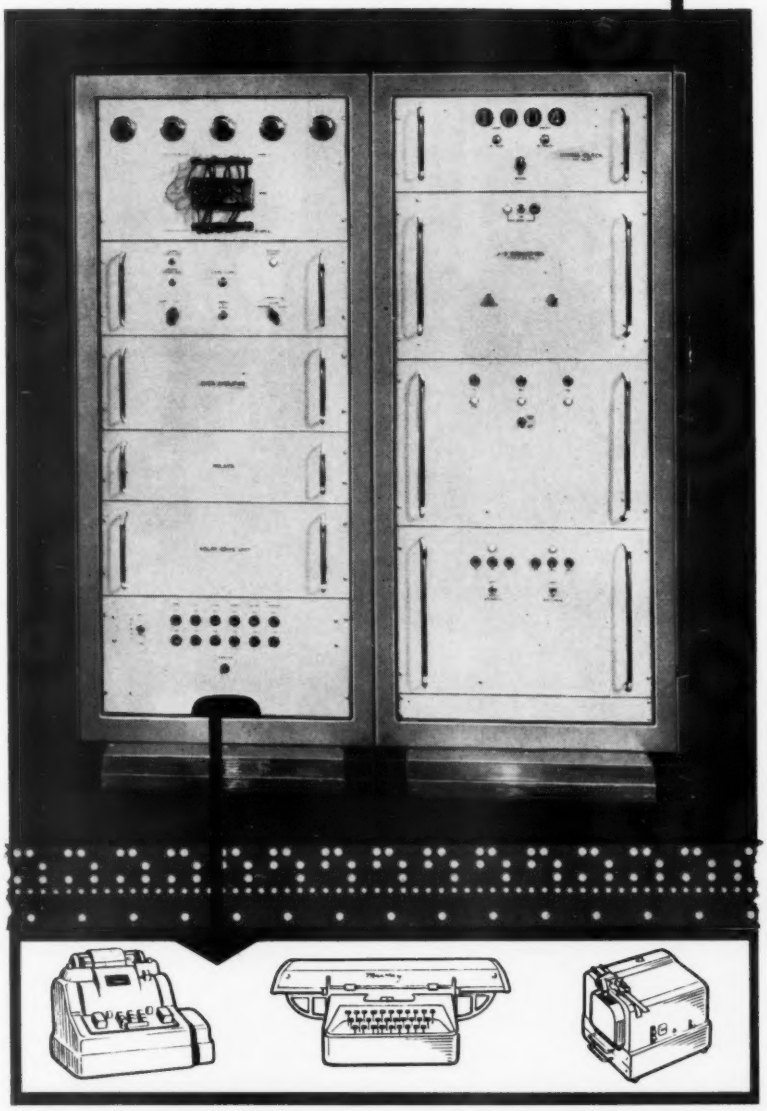

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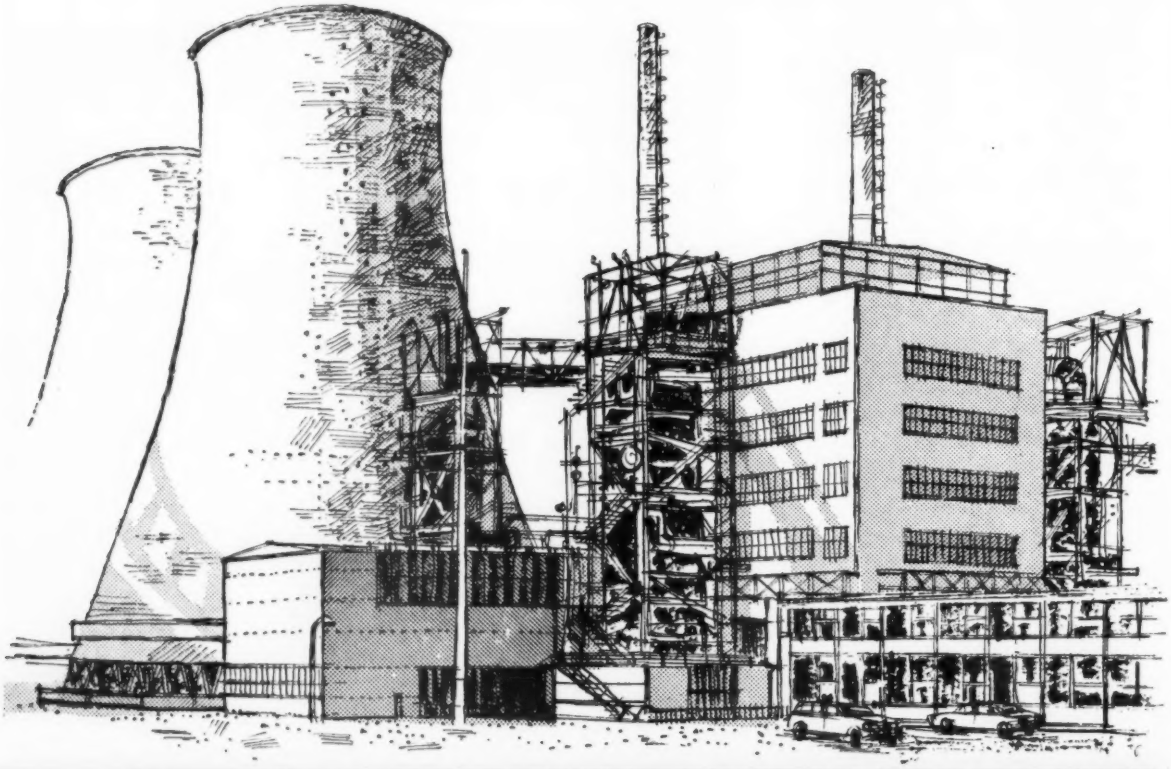

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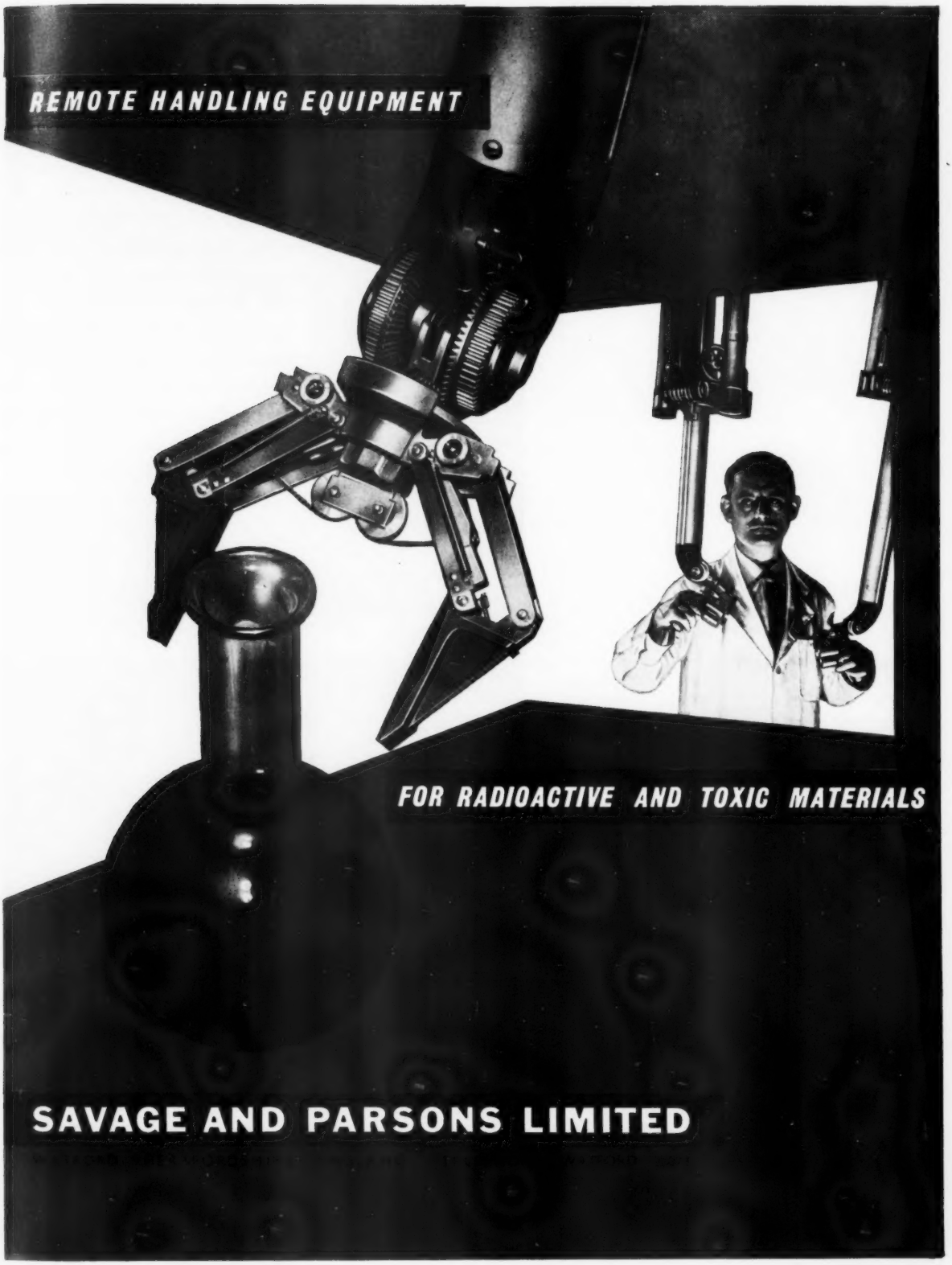
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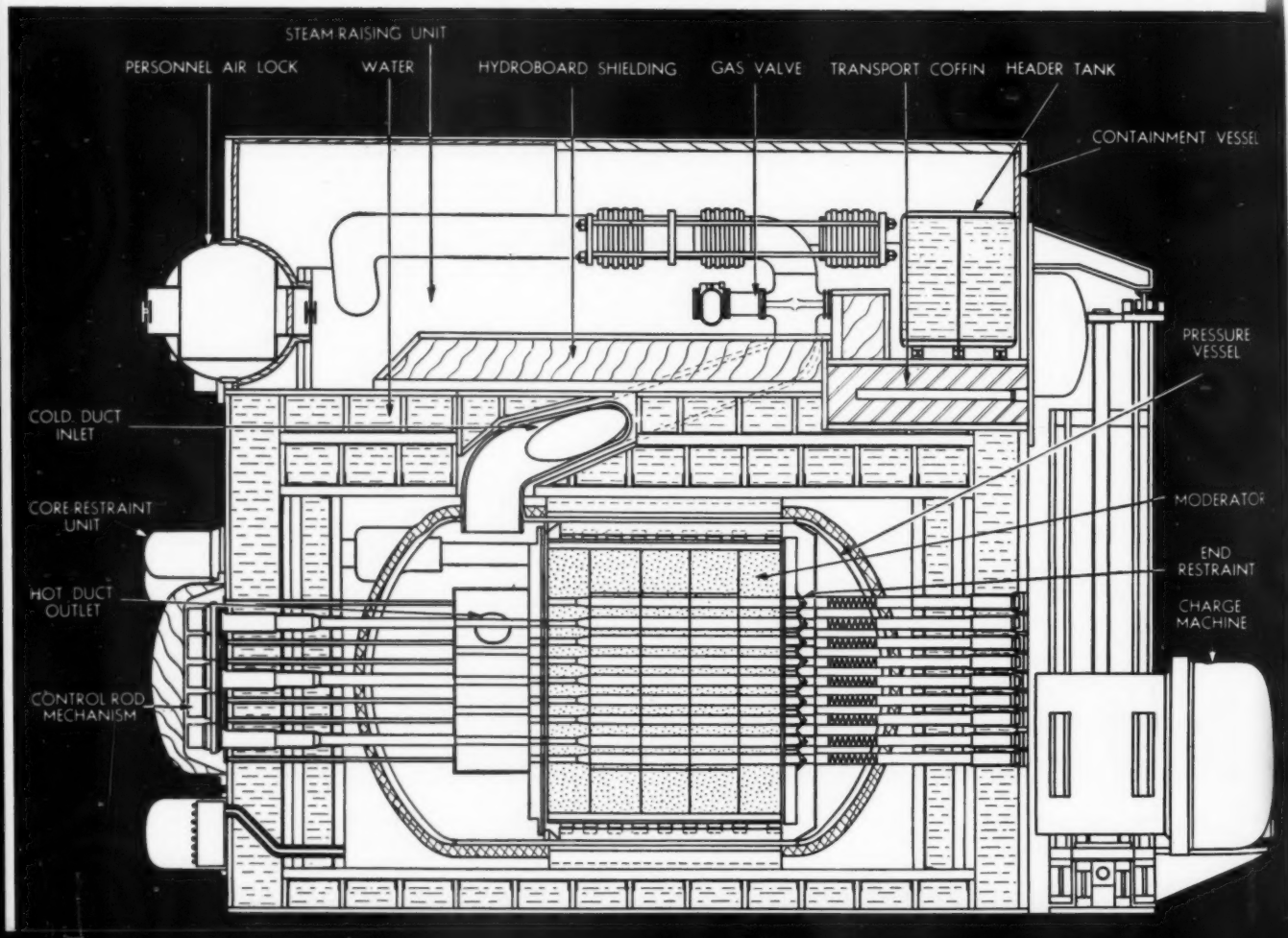
While a much wider range of applications for gas-cooled reactors can now be foreseen, perhaps the most significant aspect of this new development is that nuclear ship propulsion becomes an immediate economic possibility.

For large passenger vessels and oil tankers costs are already competitive with existing oil-fuelled engines and are likely to be reduced still further as development proceeds. A complete installation for a unit giving 20,000 s.h.p. occupies a space only 54-ft long, 35-ft wide, and 37-ft high, and weighs less than 2,000 tons, including shielding.

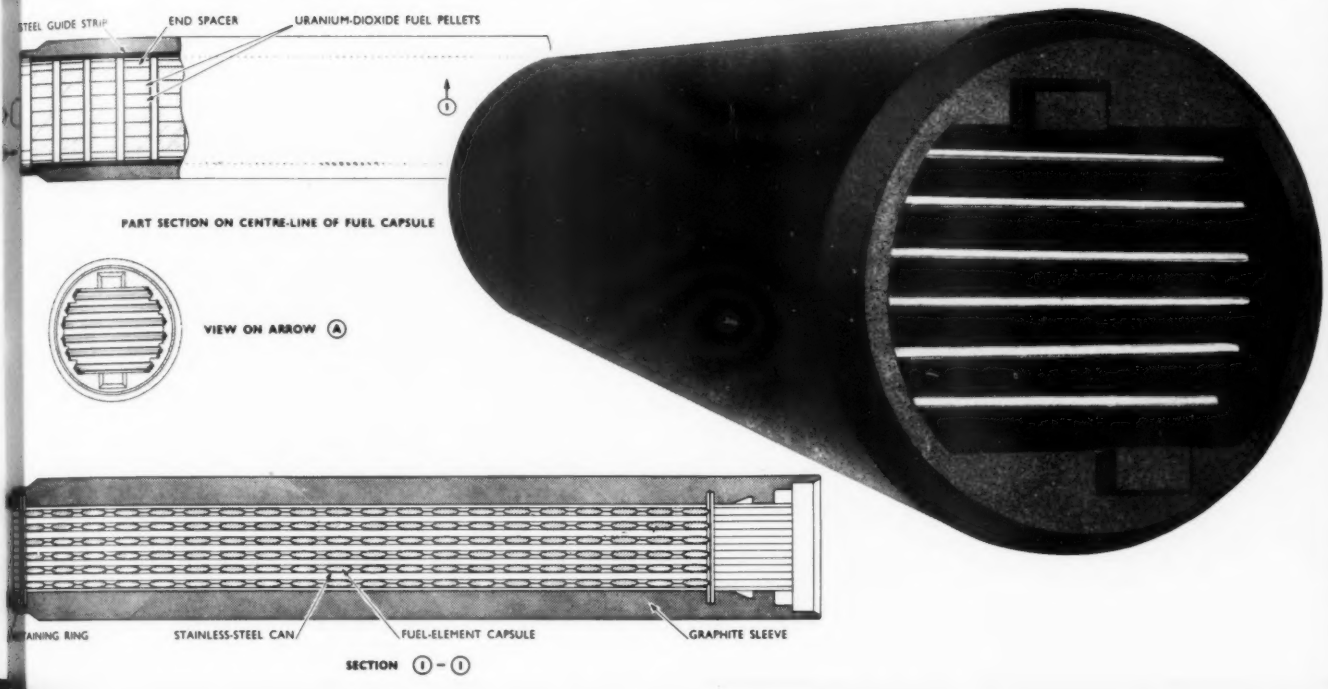
Burst-cartridge detection equipment and facilities for the removal and replacement of fuel elements whilst on load are among the design factors contributing to the safety and reliability of the installation.

A new type of fuel element is used—an element which permits the use of a much higher power density than is usual with gas-cooled reactors, and it is this feature which, more than any other, has made it possible to reduce the size and weight of the power unit so strikingly.



A NEW REACTOR

WITH A CROSS-FLOW FUEL ELEMENT



In the new G.E.C. fuel element the usual arrangement of long fuel rods is replaced by a series of short fuel capsules which are arranged at right angles to the direction of gas flow. This cross-flow design results in substantially improved heat-transfer characteristics.

Each capsule comprises a number of small uranium-dioxide pellets enclosed in a thin stainless-steel can of lenticular cross-section. A number of these capsules are welded between two stainless-steel strips to form a ladder-shaped assembly.

Several assemblies are then inserted into grooves on the inside of a graphite sleeve and held in position by steel rings at each end.

The performance of the element is not sensitive to bowing of the capsules and the simplicity of the capsule supports ensures that parasitic pressure losses are eliminated.

The use of uranium dioxide instead of uranium metal, and stainless steel instead of magnesium alloy, enables very much higher temperatures to be safely used although slight enrichment of the fuel is necessary. The more compact design made possible by the increase in power density means that higher gas pressures can be used, resulting in a further improvement in performance, and a reduction in installation capital costs.

Prospects for further development are good. For example, the use of impermeable graphite for the fuel cans would enable output to be increased still further and, because of its lower neutron absorption cross-section, would allow a decrease in the enrichment required.

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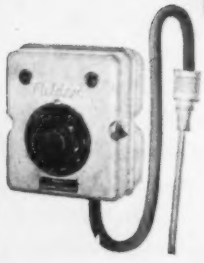

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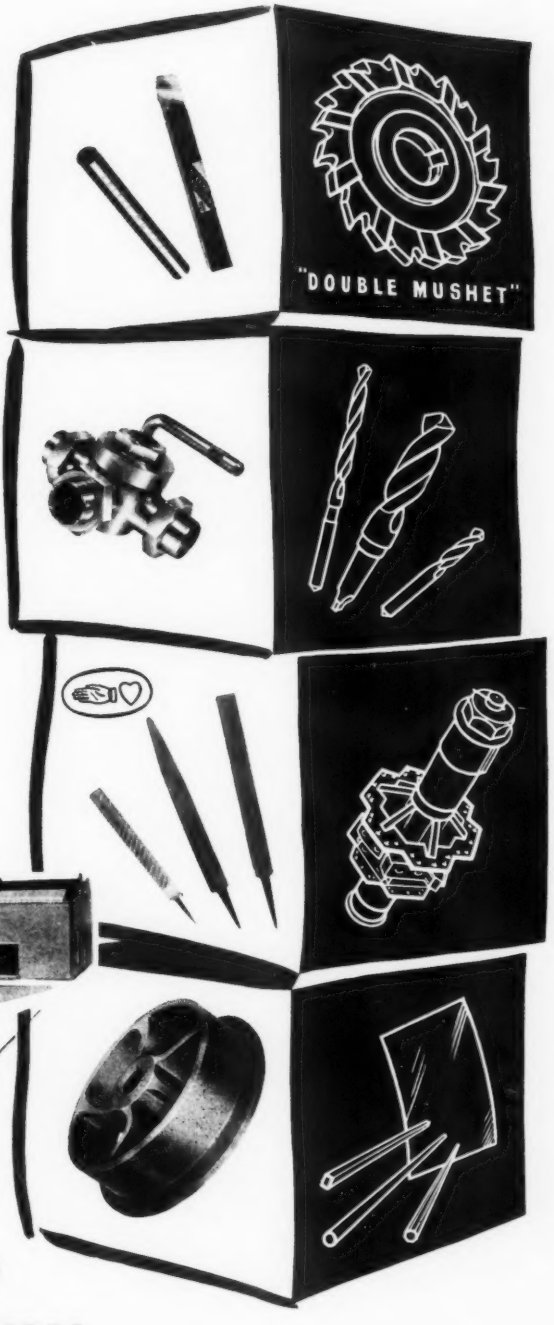

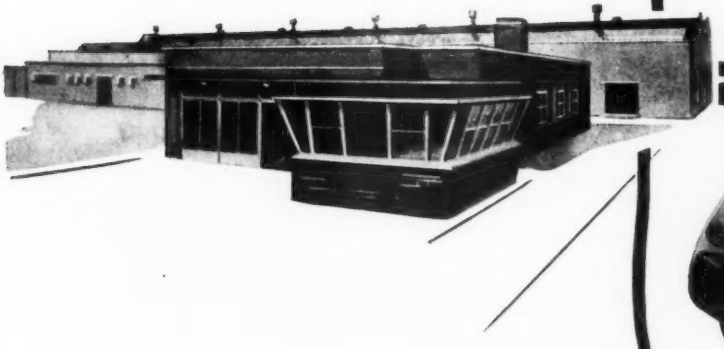

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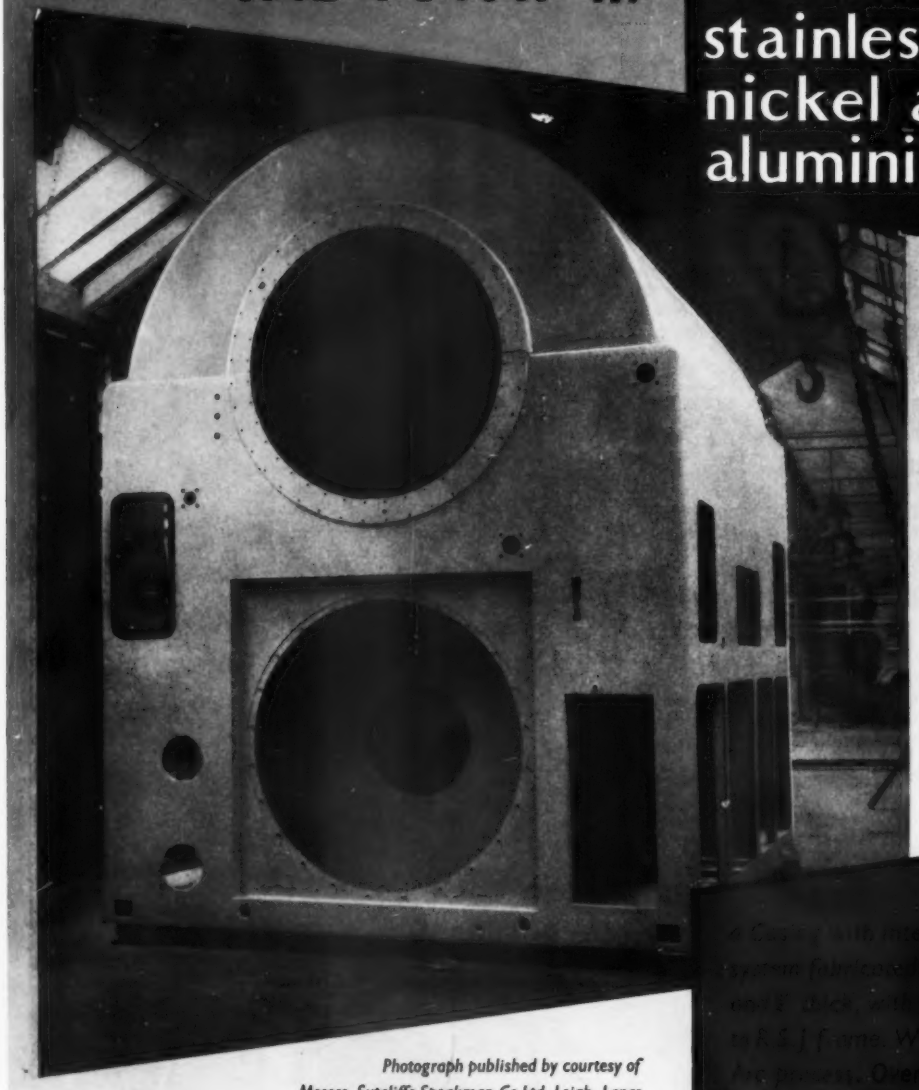

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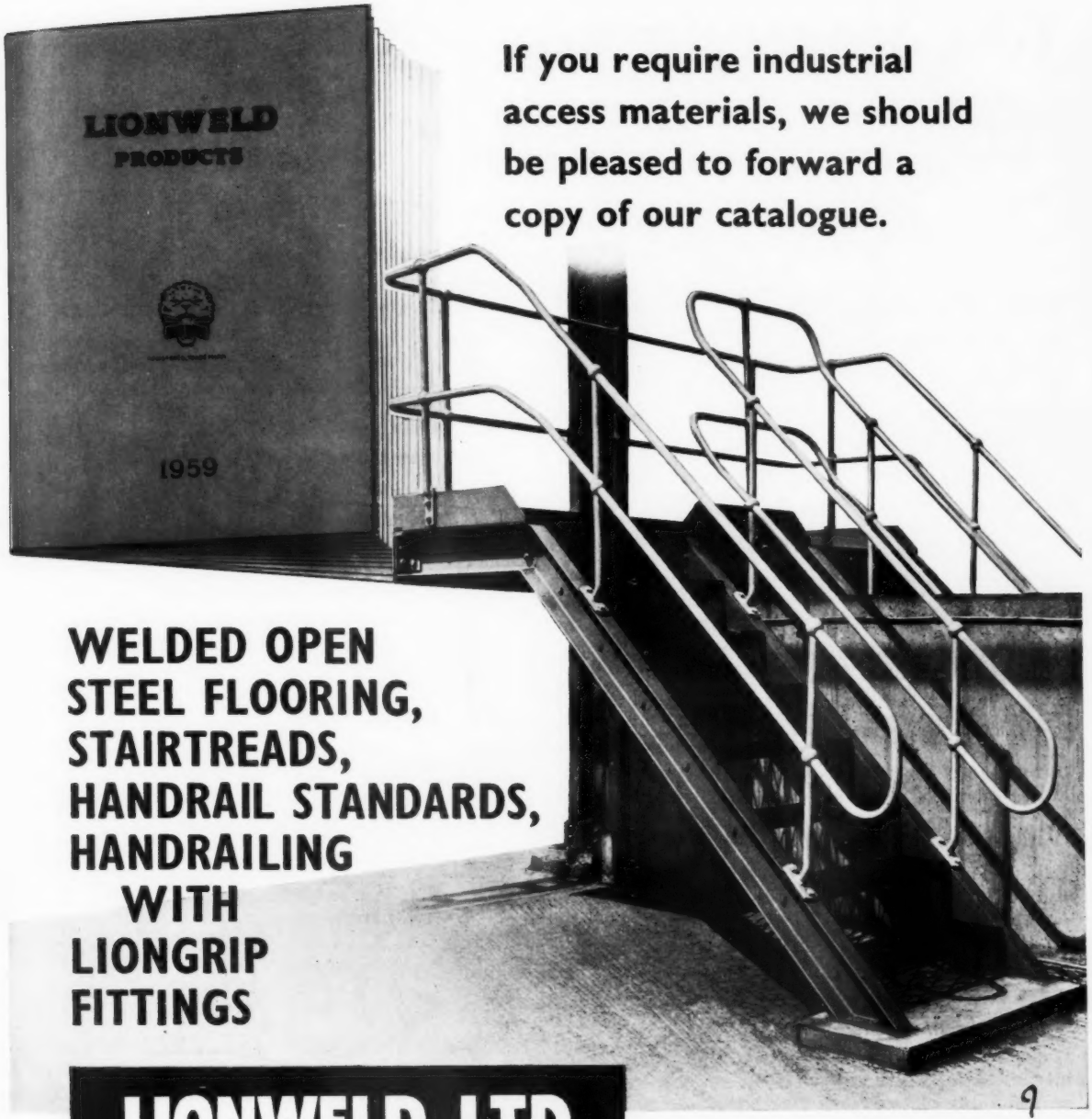

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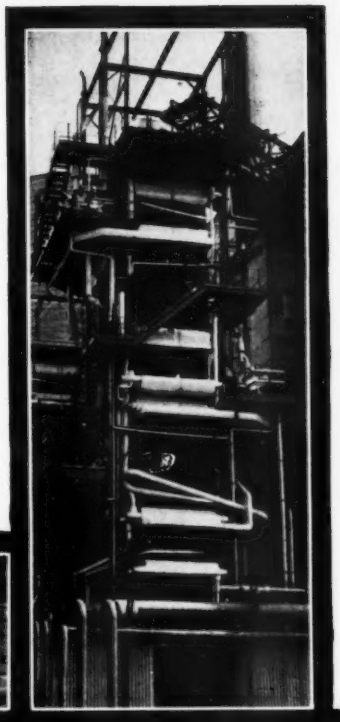

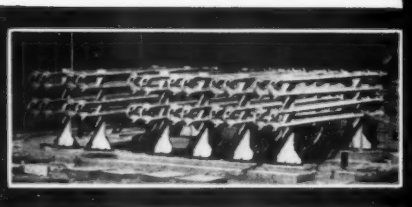

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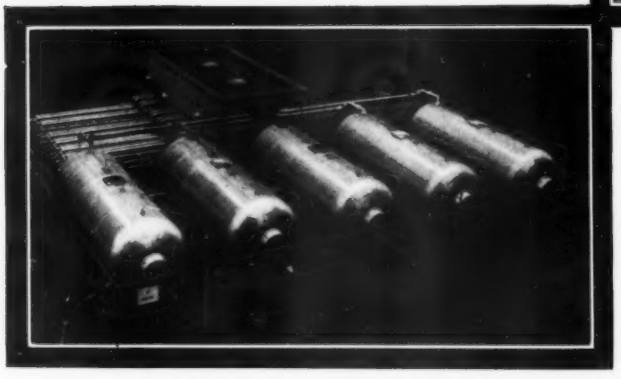


The use of carbon dioxide as a heat transfer medium in nuclear power stations raises many problems. Where storage and vaporization are concerned, The Distillers Company Limited know the answers; and they provided the installations for the purpose at both Calder Hall and Chapelcross.

Other similar, even larger, installations are now being designed or constructed by the Company for the Berkeley, Hunterston and Hinkley Point power stations. The Company has recently also obtained the contract for the supply of carbon dioxide to the Bradwell and Hinkley Point nuclear power stations.

The Distillers Company Limited
Chemical Division—Carbon Dioxide Department
Devonshire House, Piccadilly, London W.1
Telephone: Mayfair 8867

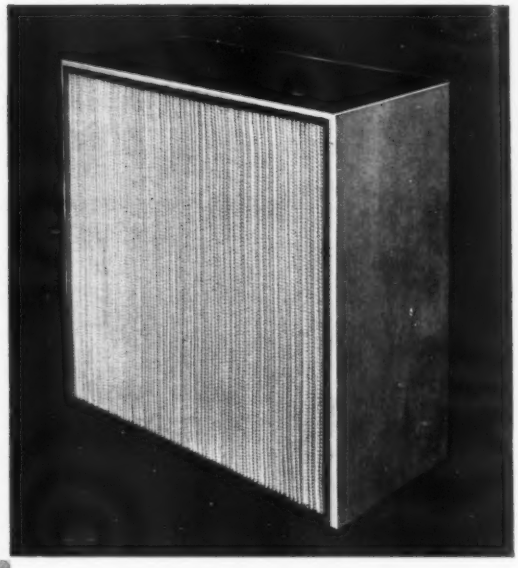
TA/2537

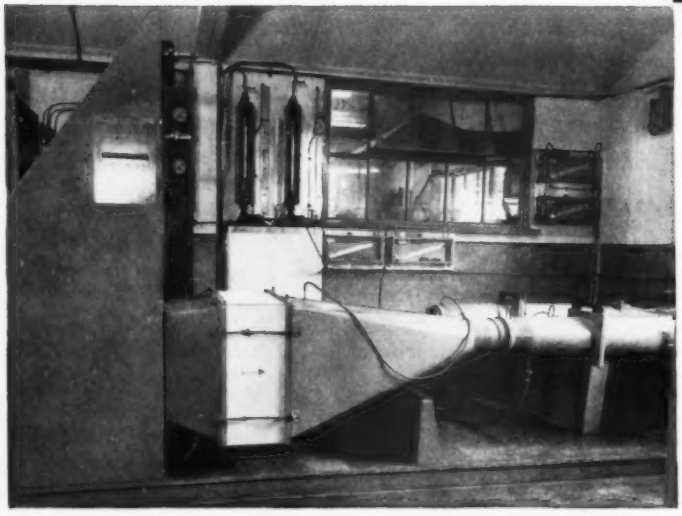
Tick **No 15** on reply card for further details

Vokes now offer flame-proof 55 'ABSOLUTE' filter panels

which fully meet U.S. Atomic Energy Commission, Bulletin 80 28/7/58 and current requirements.

Vokes filters are playing an important part in the vast programme of nuclear development both in the United Kingdom and many overseas countries. A vital contribution was the introduction of the Vokes 55 'Absolute' filter range which deals with dangerous dust particles in the 0.1 to 0.5 micron range and has a methylene blue dust cloud test efficiency in excess of 99.95% . . . **a contribution still further increased by the addition of 'Absolute' types for applications where flame-proof construction is required.** High Temperature panels are also available for use where operating temperatures as high as 1,000°F. are prevalent.





and remember . . . . . .

Initial efficiency of 99.95% against a standard methylene blue test cloud in the 0.1 to 0.5 micron range *is guaranteed*. Efficiency rises with use. Every Vokes 'Absolute' filter is fully and individually tested before despatch and is unreservedly guaranteed.

Our engineers will be glad to give you full details of the Vokes flame-proof and high temperature 'Absolute' filters and to discuss your particular problem with you, in order to ensure maximum safety operation.

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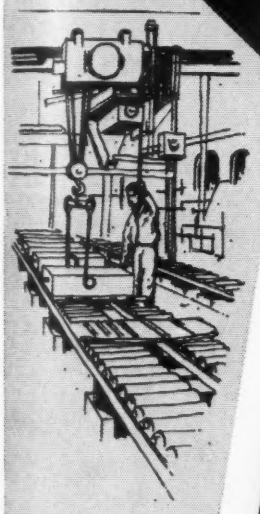
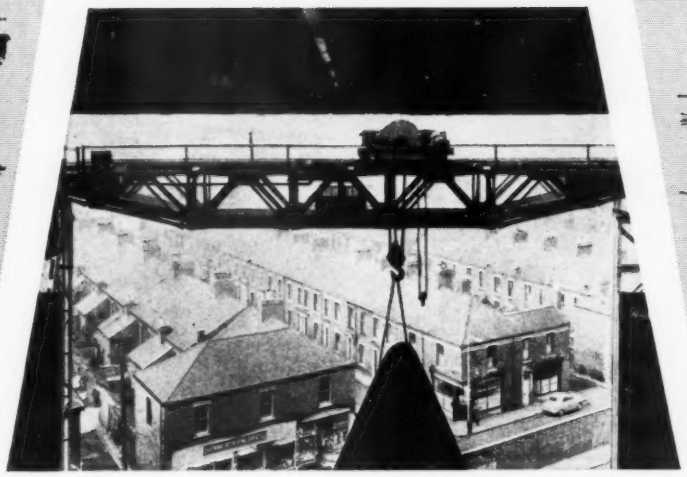
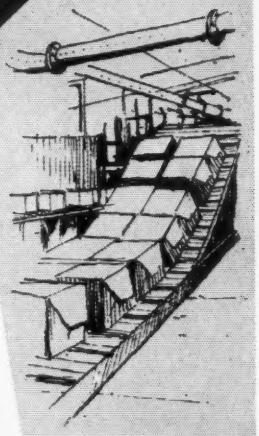




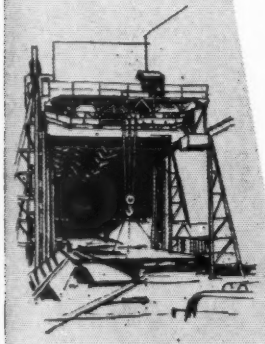


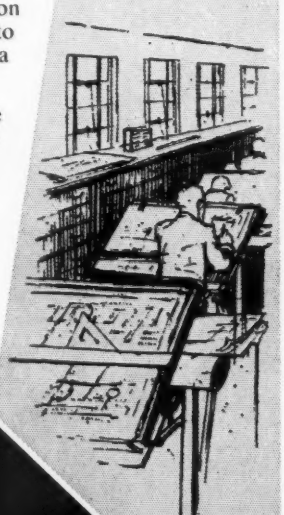
A Paterson Hughes 30-ton electric overhead travelling crane at Blyth Dry Dock and Shipbuilding Co. Ltd.—by whose courtesy this photograph is reproduced.

Paterson Hughes cranes are built in their modern crane shop in Scotland to designs based on their 35 years of experience in this field.

If the Paterson Hughes range—from hand jibs to 100-ton overhead cranes—does not include a standard model suited to your exact needs, then a special will be designed at a competitive price.

Paterson Hughes engineers will also design complete crane systems, extending from your goods inwards bay to the finished products warehouse, bearing in mind the special requirements of each industry.





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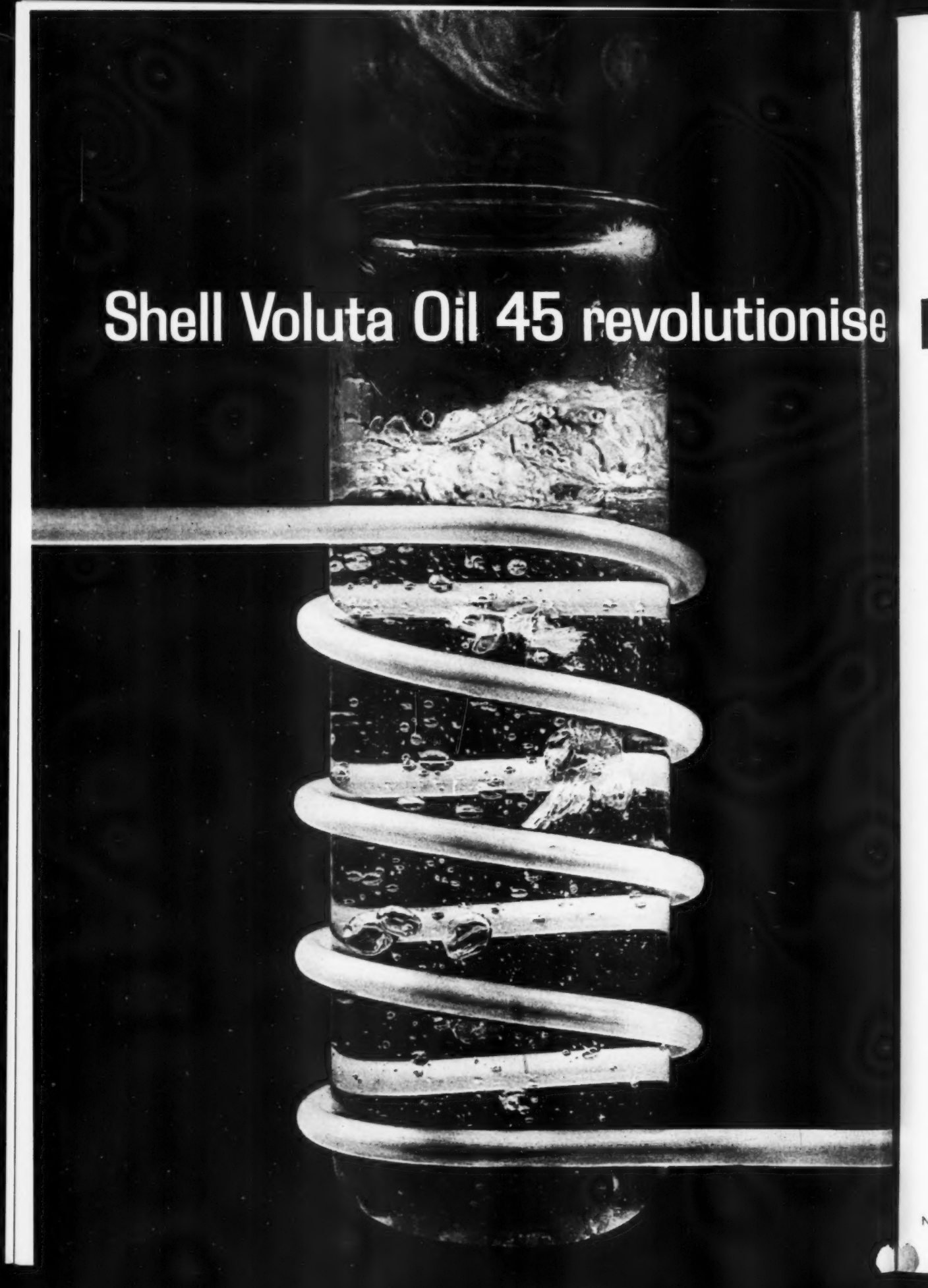
P.2114


Shell Voluta Oil 45 revolutionise

se heat exchange practice

Before Shell produced Voluta Oil 45 it was thought that oils which were to be used for heat exchange purposes must have a high flashpoint —to reduce fire risk, and a high viscosity—to prevent excessive leakage through pump glands and to provide adequate lubrication for pump bearings at high temperatures. Heat exchange systems containing these viscous oils, however, were sluggish, particularly when started up from cold. The oil circulated slowly over the source of heat and suffered thermal decomposition, or "cracking". This, in turn, produced low flashpoint materials and carbon which insulated the heating surface.

Shell, therefore, began investigating the suitability of oils of lower viscosity and different chemical constitution. From this research was developed Shell Voluta 45.

Shell Voluta 45 contains hydrocarbons with a saturated ring structure which does not have the tendency that high viscosity straight chain paraffin hydrocarbons had—to break down at high temperatures. Because of its low viscosity Shell Voluta 45 heats up more quickly from cold and circulates more rapidly thus avoiding local overheating and thermal decomposition.

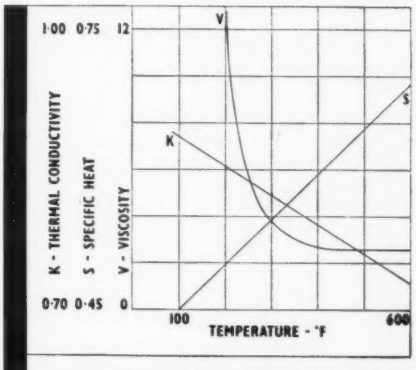
Shell Voluta Oil 45 has excellent heat transfer properties, good thermal stability and good lubricating properties. It is recommended for use in all closed heat transfer systems.

The moral of the story is that Shell research is supremely applicational. The centre at Thornton is always ready to work with even the most specialised sectors of industry to produce the right oil for the job. If you and your organisation have any major lubricating problems, it pays to get in touch with your local supplier of Shell Industrial Lubricants.

The Research Story

Laboratory research to compare the high temperature performance of various oils in a rig simulating practical conditions showed that when oils of varying viscosities were maintained at an average temperature of 325°C. for 200 hours, the closed flashpoint of the high viscosity oils had dropped to a lower figure than that of oils of lower viscosity, indicating that some thermal decomposition had taken place.

Experimental oils were subjected to Heat Stability Tests and to tests designed to measure the variation in heat transfer coefficient with time. The most promising of these oils was then given extensive field trials, both in Shell Installations and in industry. From this extensive research was developed Shell Voluta 45.



Physical properties of Shell Voluta Oil 45.
K. Thermal Conductivity—B.T.U./sq. ft. per hour per 1°F. per inch.
S. Specific Heat—B.T.U. per lb. per 1°F.
V. Viscosity—Kinematic centistokes.

SHELL

HEAT TRANSFER OILS

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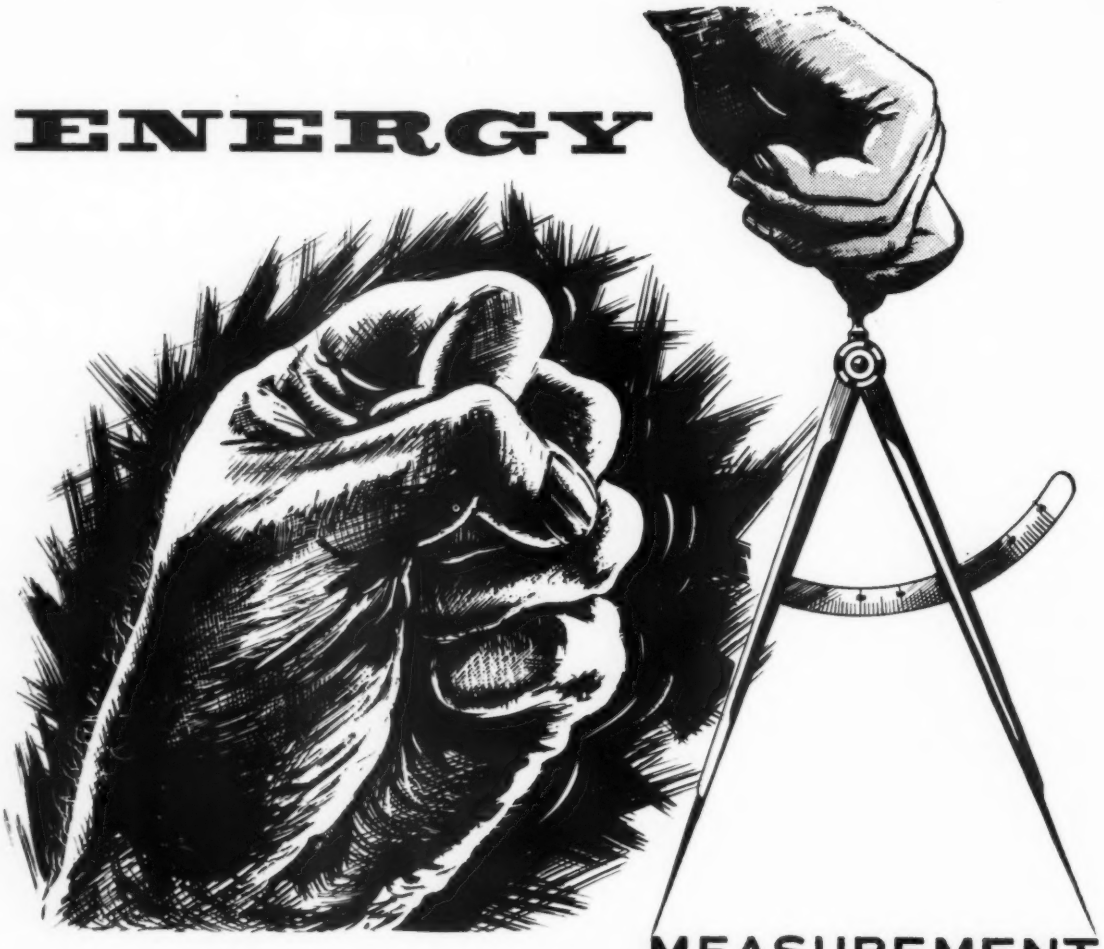
ENERGY



MEASUREMENT

and CONTROL

G. R. will be a familiar name in the control rooms of Europe's Nuclear Power Stations. The staff of coal or oil fired Power Stations do not require to use the names 'neutron flux' and 'nuclear fission'; these and words like 'general radiological' are important to Nuclear Power Station control staff . . . so are 'reactor flux stability' and 'demanded reactor power'. For the Nuclear Station operators the satisfactory performance of the reactors in relation to the demanded station power, will be integrated with that of the heat exchangers and turbines in the

OVERALL AUTO-CONTROL SYSTEM.

G.R. has been awarded the contract for the design and manufacture, in conjunction with C. A. Parsons & Co. Ltd., of the Automatic Control Instruments to be installed by the Nuclear Power Plant Company at Bradwell.

general radiological ltd.

NUCLEAR ENGINEERING DIVISION

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NEW I·D·L

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'1800 SERIES'

These low-priced, space-saving units give full operational accuracy, flexibility in application, and simplicity of maintenance. Details of the first three units – the Scaler Type 1800, H.V. Supply Type 1820, and Amplifier/Selector Type 1830 are given here. *Watch for details* of the Prescaler 1850, Ratemeter 1810, Potentiometer 1840, and Timer Unit 1860.

THE '1830' AMPLIFIER-SELECTOR

Amplifier:
Gain: x 5: x 200: x 1,000.
Input Impedance: 1 mA.
Rise Time: 250 m/μ sec.
Stability: 1%.

Discriminator/Selector:
Threshold: (variable) 5 to 50 V.
Stability: ± 0.25 V.
Channel Width: (variable) 1–50 V.
Stability: ± 0.25 V.

THE '1820' H.V. SUPPLY

Voltage and Current output: (Positive only).
Range 1: 250 to 1,000 volts. 0.3 mA.
Range 2: 500 to 2,000 volts. 0.1 mA.
Stability: (For Mains change +5% to −15%: 0.25%)
Maximum ripple (peak to peak): 50 mV
Controls: Coarse: "off", "range 1", "range 2". Fine: continuous.

THE '1800' SCALER

Count Capacity: 99,999 counts
Max Count Rate 4,000/sec. (evenly spaced pulses)
Resolution Time: 275μ sec.
Input Sensitivity: 5 volts + ve.
Input Impedance: .01μF into 470 k.

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- Every Unit has 100 hours test before despatch.
- More than 90% of Tubes internationally available.
- Fully detailed service Manual.
- Packaged Spares Kits available.

If you are interested in nucleonic counting, but also have to count the pennies and the cubic feet, you should find out more about the I.D.L. '1800 Series'.

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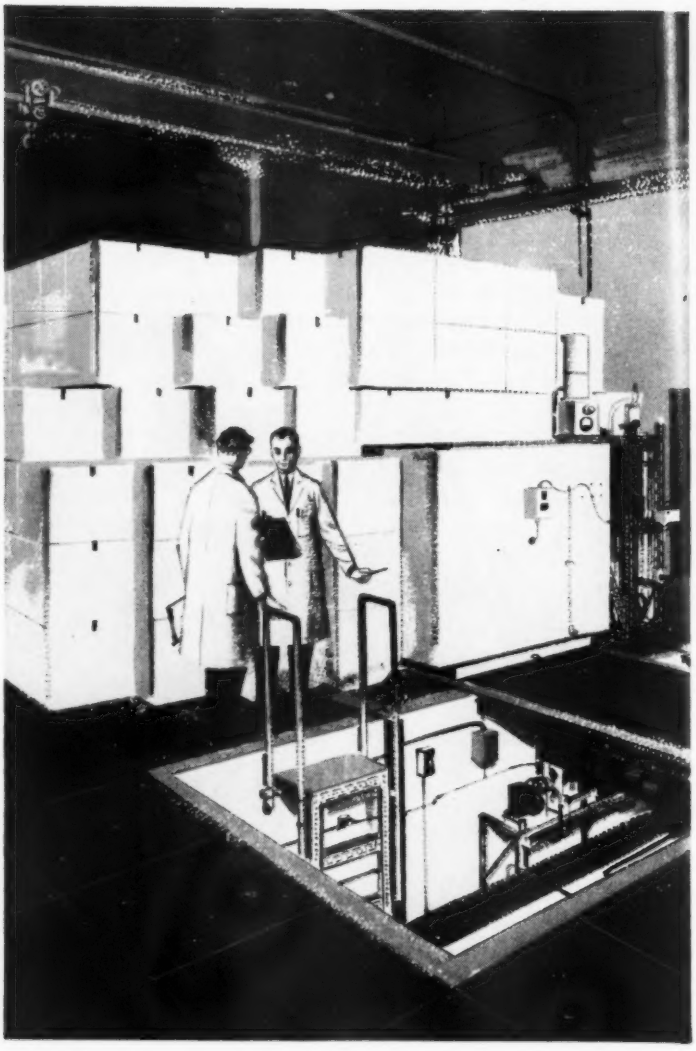

JASON

THE PRACTICAL REACTOR FOR RESEARCH AND TRAINING

Hawker Siddeley's Jason reactor provides a large source of neutrons at low power, is ideal for student training and activation experiments and for the production of short lived isotopes for medical research. The Jason, which is basically similar to the Argonaut, has five forms, offering a wide range of facilities and powers from 1 to 20,000 watts. Around the central annular core in the cubic graphite reflector can be placed a shield tank, beam holes, thermal columns or lattice experiments up to four in number. A further lattice experiment can be placed above the core. Using 20% or 90% enriched uranium, the flux ranges up to 3×10^{11} n/cms^2. sec.
The standard Jason is now operating at Langley.

Other products include: Organic Reactors for ship propulsion, power generation and heat production. Radio-chemical and radio isotope laboratories, and associated equipment.

Please write to Box N.P.1

HAWKER SIDDELEY NUCLEAR POWER CO. LTD

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CAST IRON VESSELS

for the

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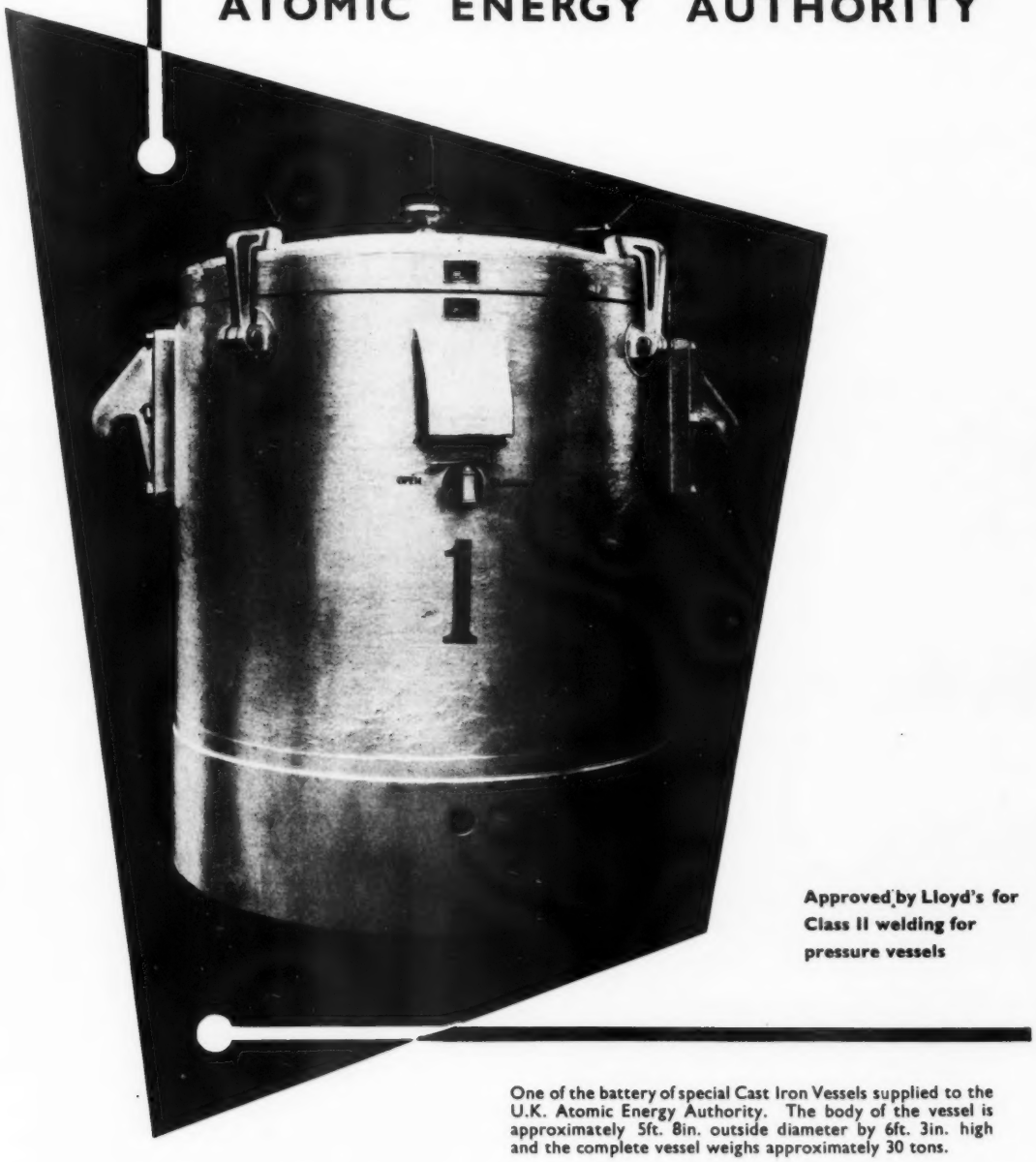

Approved by Lloyd's for Class II welding for pressure vessels

One of the battery of special Cast Iron Vessels supplied to the U.K. Atomic Energy Authority. The body of the vessel is approximately 5ft. 8in. outside diameter by 6ft. 3in. high and the complete vessel weighs approximately 30 tons.

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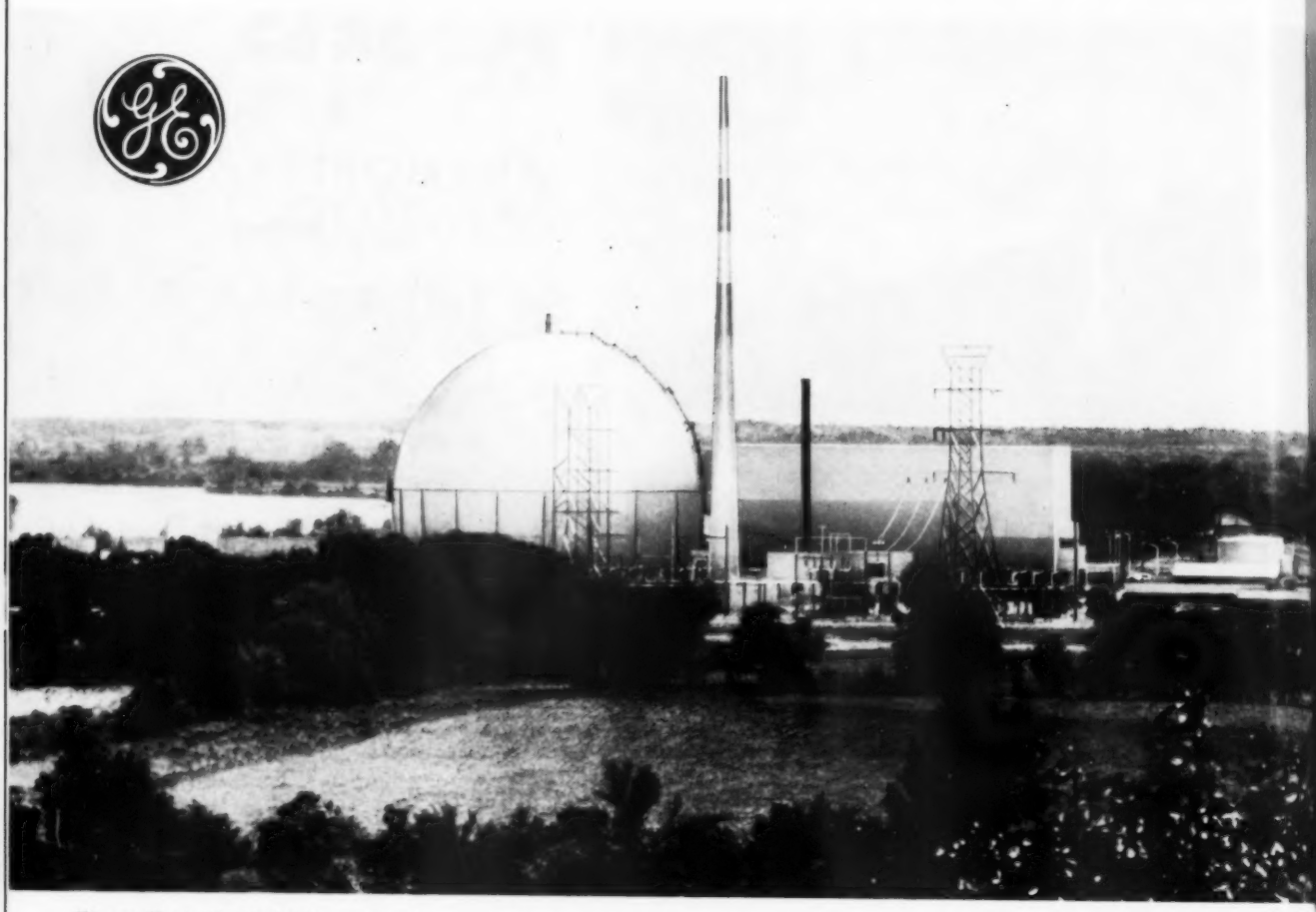
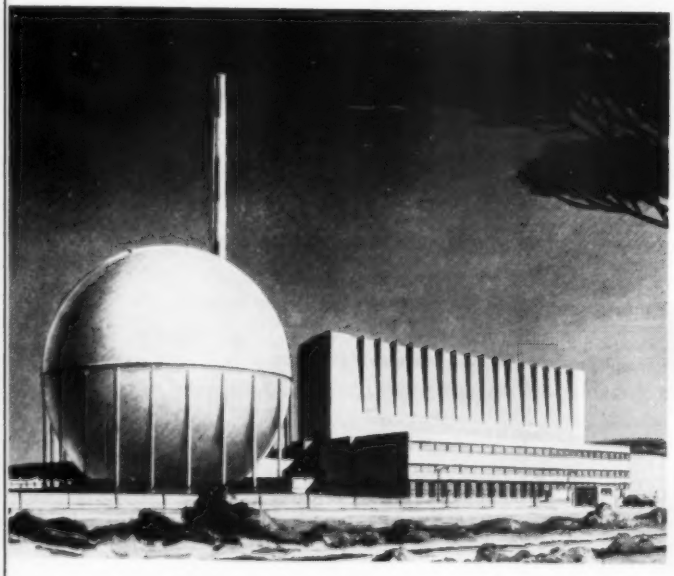
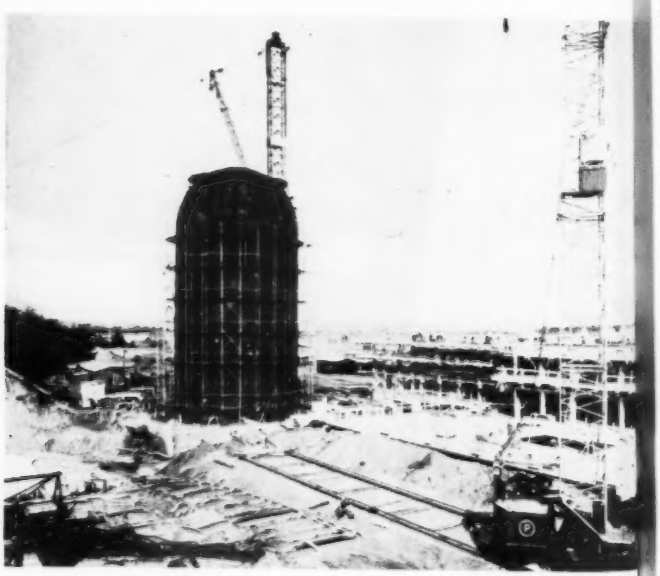
GENERAL ELECTRIC BWR



Chicago, Illinois. The 180,000-kilowatt Dresden Power Station has now "gone critical." Currently 6 months ahead of schedule, the new plant will be producing enough electricity by the summer of 1960 to supply the needs of a city of 200,000 people. Dresden utilizes General Electric's dual-cycle boiling water reactor.



Rome, Italy. Construction has started on the 150,000-kilowatt Garigliano Nuclear Power Plant for the Societa Elettronucleare Nazionale (SENN), which is scheduled to be completed in 1963. The plant will utilize a G-E dual-cycle boiling water reactor. Shown above is an artist's sketch.



Frankfurt, Germany. RWE, one of Europe's largest utility companies, announced that construction is progressing on the country's first nuclear power station. G.E. is supplying the nuclear reactor steam supply system which includes a 15,000-kilowatt (e) BWR. The Kahl plant is scheduled for operation late in 1960.

"GOES CRITICAL" AT DRESDEN!

U.S.A.'s largest nuclear power plant 6 months ahead of schedule...full operation slated for mid-1960

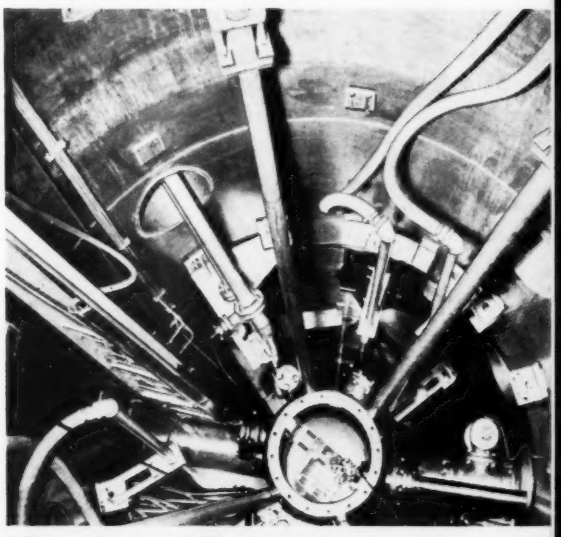
On October 15, 1959, the reactor at Dresden Power Station, designed and built by General Electric for the Commonwealth Edison Co. and co-sponsoring Nuclear Power Group, sustained its first chain reaction. This put the nation's largest all-nuclear power plant into operation 6 full months ahead of schedule. Criticality at Dresden marked the beginning of an exhaustive series of reactor tests leading to initial production of electric power early in 1960, and full operation by mid-year.

General Electric has been selected to build boiling water reactors for several other plants around the world: Societa Elettronucleare Nazionale (SENN) in Rome, Italy (150,000 kw); Rheinisch-Westfälisches Elektrizitätswerk in Frankfurt, Germany (15,000 kw); Consumers Power in Michigan, U.S.A. (50,000 kw); Pacific Gas and Electric Co. (Humboldt Bay) near Eureka, California, U.S.A. (50,000 kw), and the Japan Atomic Energy Research Institute in Tokyo (12,500 kw). General Electric was awarded these reactor orders because (1) it is expected that the G-E boiling water reactor will provide the lowest power costs of all the current reactor concepts, (2) the simplicity of the system makes lower capital investment possible, and (3) the advanced research and development on the design and manufacture of oxide fuel elements enables G.E. to guarantee high fuel burn-up levels.

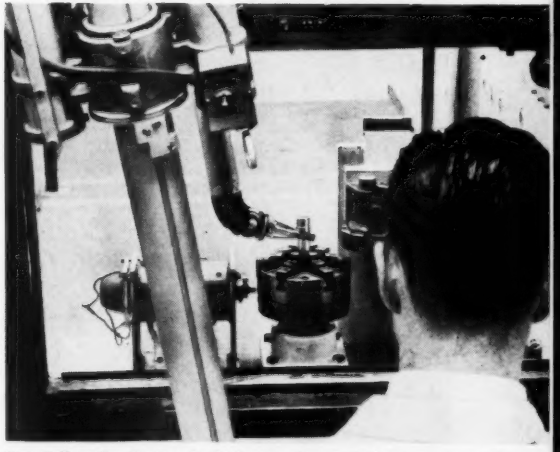
Complete Nuclear Irradiation Service

As part of its complete nuclear irradiation services, General Electric's Atomic Power Equipment Department has available the most complete, privately-owned nuclear research facilities in the world at its Vallecitos Laboratory. These integrated irradiation research and development services range from basic and applied nuclear research programs to testing and development operations requiring specialized experience and equipment. *Space in the General Electric Test Reactor is available to you for your irradiation needs. Write for bulletin GEA-6934.*

Let General Electric's extensive atomic facilities and experience in the nuclear power field help you in the application and technical advancement of atomic energy. For further information, contact International General Electric S.A., 81 Route de l'Aire, Geneva, Switzerland. Or write: *International General Electric Co., Dept. 59-95, 150 East 42nd St., New York 17, N.Y., U.S.A.*



Vallecitos, (San Jose), California. Photo from above pressure vessel of G-E Test Reactor, rated 30,000-kw (t), shows top of reactor, in-core loop facilities, capsule lead tubes, and leads from ion chambers. Extreme flexibility, capacity, and wide flux range make it possible to elminate long waits by irradiation customers for "in time"—make high neutron fluxes available to industry—immediately.



Hot Cell Lathe Station in Vallecitos Atomic Laboratory remotely performs cutting, turning, and other similar operations on irradiated materials. Approximately 21,000 square feet of Laboratory floor space are devoted to test cells and supporting operations, including an instrument shop, decontamination and manipulator repair rooms, a "hot" chemistry laboratory, and a photographic laboratory.

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—U.S.A.—

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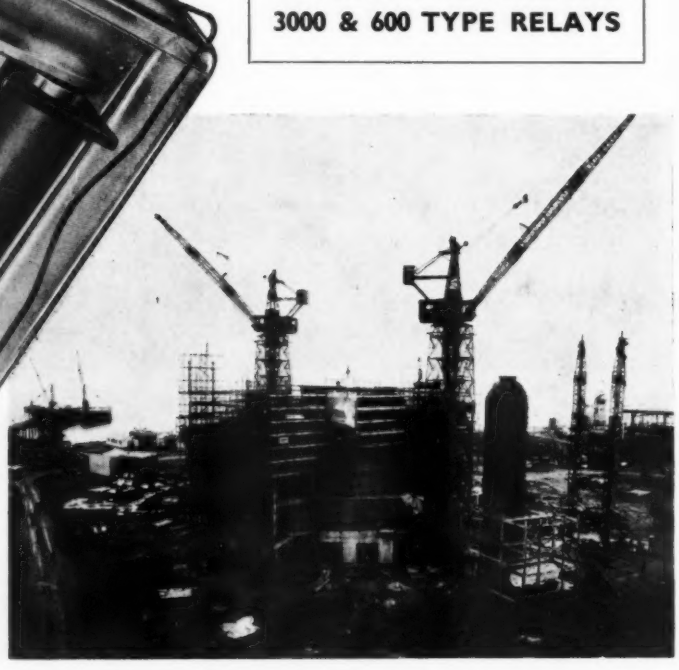
3000 & 600 TYPE RELAYS



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FOR MINIMUM MAINTENANCE.
Replaceable cylinder and crosshead liner eliminate rebores, cut maintenance time, restore 'new' performance. Self aligning main bearings and box-type cross-head guides for low loading, long life.

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Oversize spherical roller main bearings. Durable construction embodies stainless steel valves, steel piston rods, replaceable liners, aluminium pistons, mehanite frame.

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SPECIAL JOBS — SPECIAL MODELS
Oil-free versions for food and chemical industries — low-pressure models for specialised applications — skid-mounted types where portability is required . . . . JOY SULLIVAN can match most individual requirements from the WN series.

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...read the fact-packed* JOY WN.112 *Catalogue
All you wish to know about WN.112 compressors is contained in Catalogue AD/6. A copy will be sent immediately on request.

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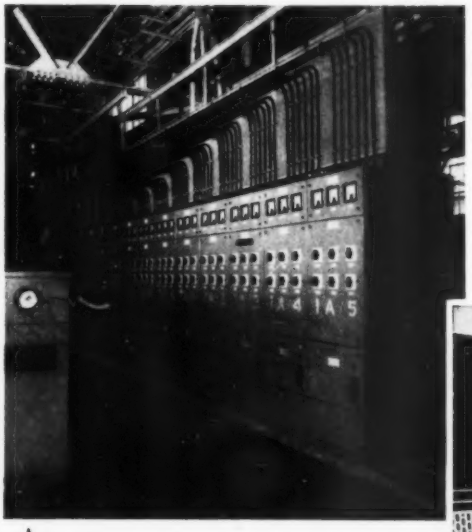
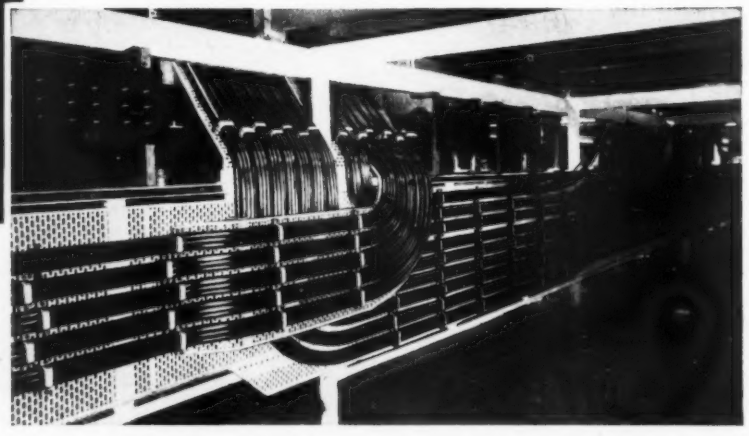
serves the Atomic Age....



Men are working on the lonely coasts of Britain, and vast and unfamiliar structures are rising to provide the Nation's new electrical power sources.

This is visible progress. Yet, in the changing scene there are constants. Pyrotenax M.I.C.C. Cables, for instance, have been the consistent choice of electricity supply authorities for years. Twenty years ago the most "modern" power stations installed "Pyrotenax"—and the same original cabling still serves today. Little wonder that in this present age too, "Pyrotenax" is being specified for the lighting and power services in the various automic plants of the United Kingdom Atomic Energy Authority. Current *generating* may change, but current *carrying* is always best left to "Pyrotenax"!

Main control switchboard at one of the United Kingdom Atomic Energy Authority Research Establishments showing Pyrotenax cables feeding lighting, power and instrument circuits.



Power and instrument cabling at the rear of the main switchboard. (Contractor N. G. Bailey Limited Leeds.)

PERFECTED BY EXPERIENCE

Pyrotenax

m.i. COPPER COVERED CABLE

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non-fire causing—heat resisting—moisture-proof—non-ageing—rust-proof—safe against overload—resistant to mechanical maltreatment—resistant to noise transmission—

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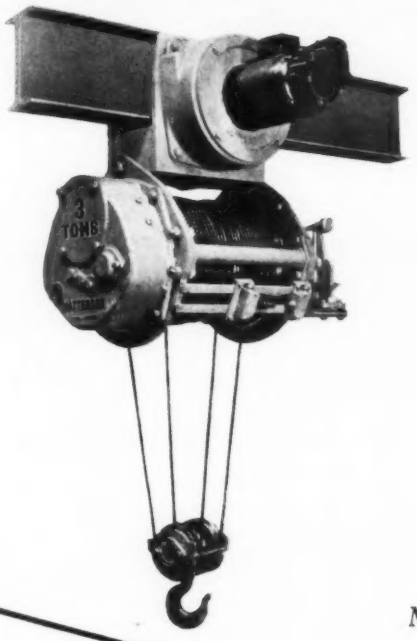
GD 127



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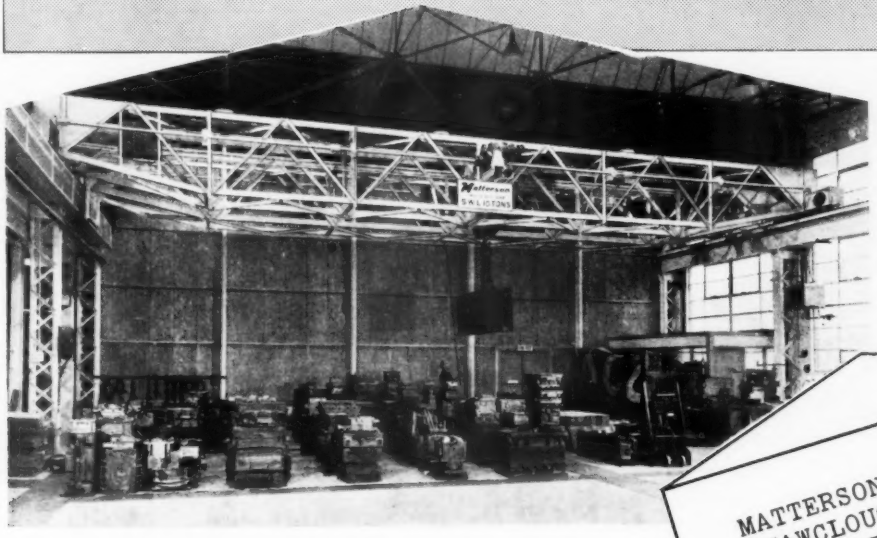

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PHOTOMULTIPLIER TUBES

The VMP 11/44/A is a 2″ diameter photomultiplier incorporating a Cæsium Antimony photocathode of high sensitivity and a venetian blind photomultiplier structure. The high cathode sensitivity and good collection efficiency make this tube extremely suitable for γ-ray spectrometry. The energy resolution which can be achieved is a function of both a scintillator crystal (NaI(T1)) and the photomultiplier and the accompanying graph shows the resolution obtained with a typical tube-crystal combination on the spectrum of Cobalt 60. The peak to valley ratio obtained is 3 : 1.

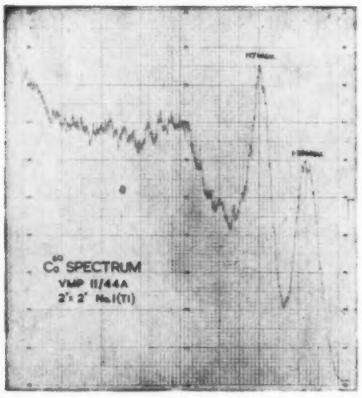
To obtain the maximum stability required for high resolution spectrometry it is recommended that temperature control is provided for the counting assembly and that the mean current in the photomultiplier at the maximum counting rate does not exceed 0.1 μA.

Type	Cathode Type	CHARACTERISTICS (AVERAGE)			
		Cathode Sensitivity μA/Lumen	Overall Sensitivity A/Lumen (S)	Overall Voltage	Dark Current at S
VMP 11/44A	S11	55	2,000	1,400	0.08μA

PROPORTIONAL COUNTERS

The resolution of the proportional counter for energies below 100 KeV is superior to that of the scintillation counter and the type PX.115 has been designed to extend the range of high resolution spectrometry down to 20 KeV. The energy resolution obtained with this tube in measuring the γ-radiation from Americium^{241} (59.4 KeV) is 6% compared with 16% with a typical scintillation counter. The proportional counter has found particular application in the analysis of fission product spectra.

Type	Diameter	Gas Filling	Gas Pressure Cms. Hg.	Operating Voltage Range (volts)	Gas Multiplication Factor volts/db
PX.115	2½″	Xenon-Methane	150	3,000-4,000	60



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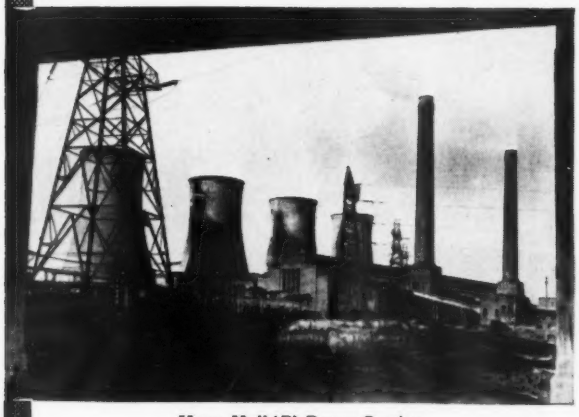
The condensers of numerous power stations and oil refineries at home and abroad owe much of their efficiency to being fitted with tubes from one of these old established companies.

The choice of alloy for any specific installation is most important. The Delta Group range of non-ferrous tubes has been specially developed to suit the varying conditions which have to be met in service and our Research Department is always glad to carry out tests and advise customers on the most suitable composition for their requirements.

Two plants that have installed Delta Group Tubing



Hams Hall 'B' Power Station.

B.P.'s Aden Refinery.
Photo: Courtesy The British Petroleum Co. Ltd.

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TUBE DIVISION

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REGISTERED TRADE MARKS:
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TGA JBG144

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Stillite thermal and acoustic insulation is completely fireproof, vermin proof, rot proof and damp repellent. Available in a range of forms for roof and suspended ceiling insulation, partitioning and as fire protection to vital support girders.

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Regd. Trade Mark

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Whitehall 0922-6 ***and at:*** **231 St. Vincent Street, Glasgow, C.2.** ***Central 4292***

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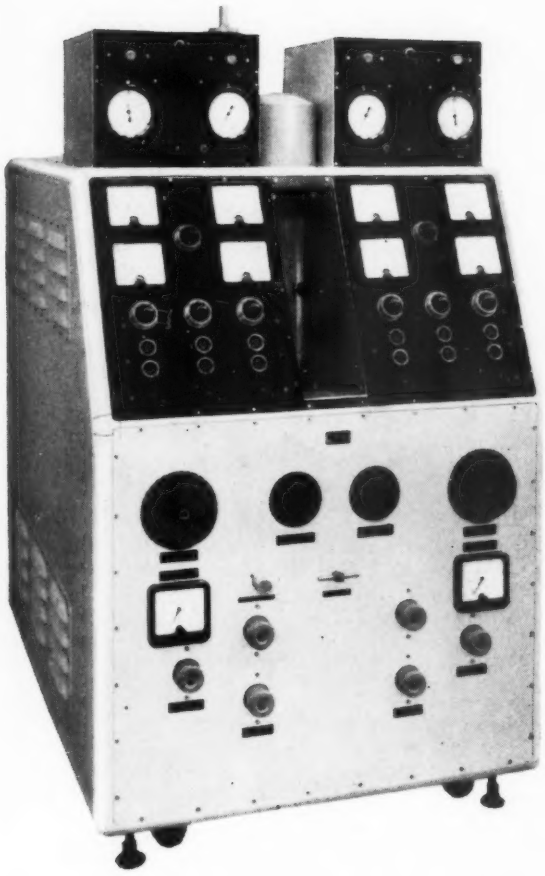

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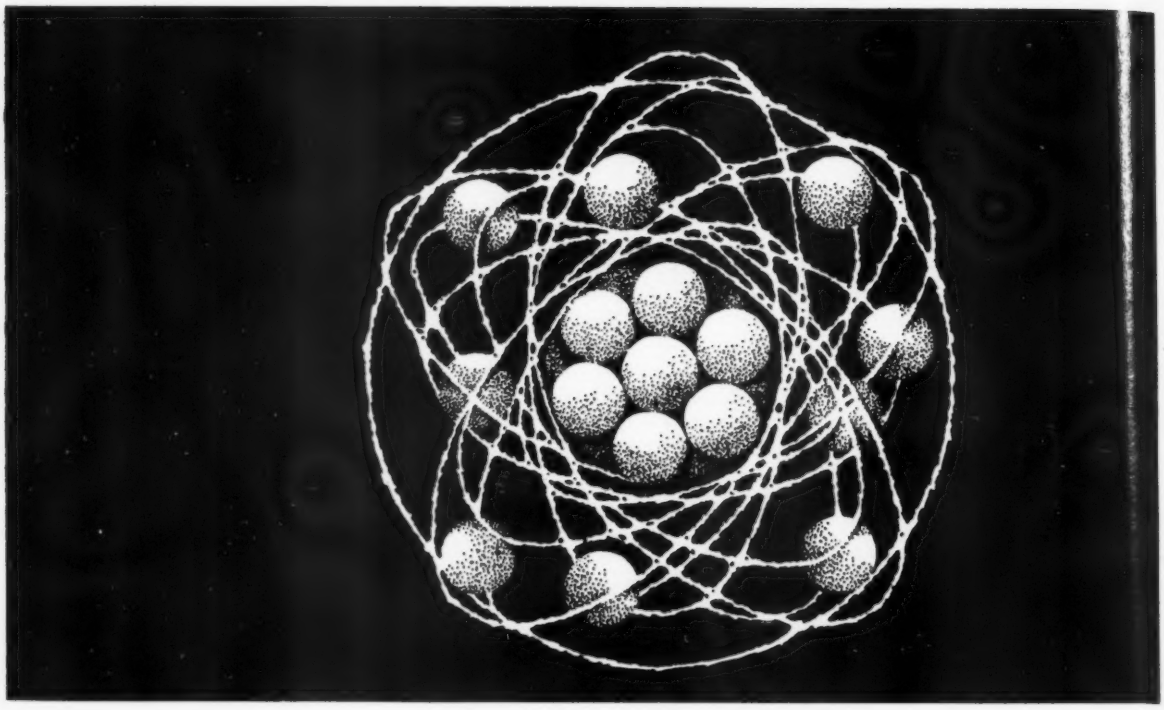

Main CO_2 Duct Isolating Valve for Nuclear Reactor Power Plants for working pressures of 10 kg/cm^2 and 400° C.

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The design of the ERHARD-Absperrklappen is not limited to the aforementioned temperatures and pressures, and we are in a position to manufacture valves in order to meet the severest temperature and pressure conditions arising in nuclear reactor power plants.

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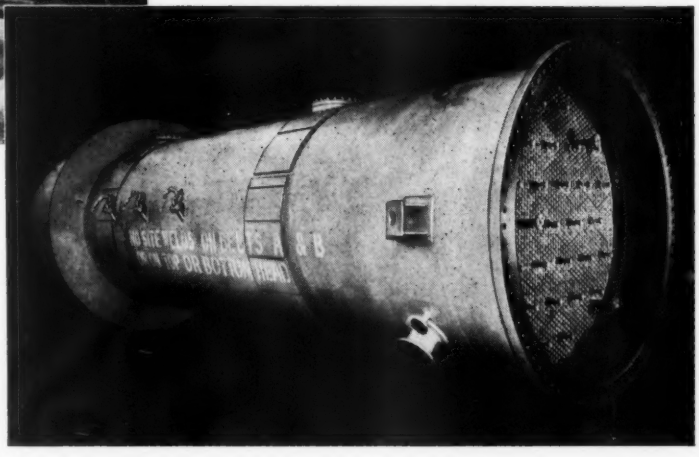
Harvey engineers are always available to discuss your fabrication problems, and to advise how we can best help you.

Left: A mild steel jacketed Autoclave to Class 1 construction with electrically driven stirring gear.

Below: This Ethylene Oxide Reactor weighs 135 tons, is 9 ft. 6 ins. in diameter and contains over 15 miles of 1¾ in. dia. catalyst tube.



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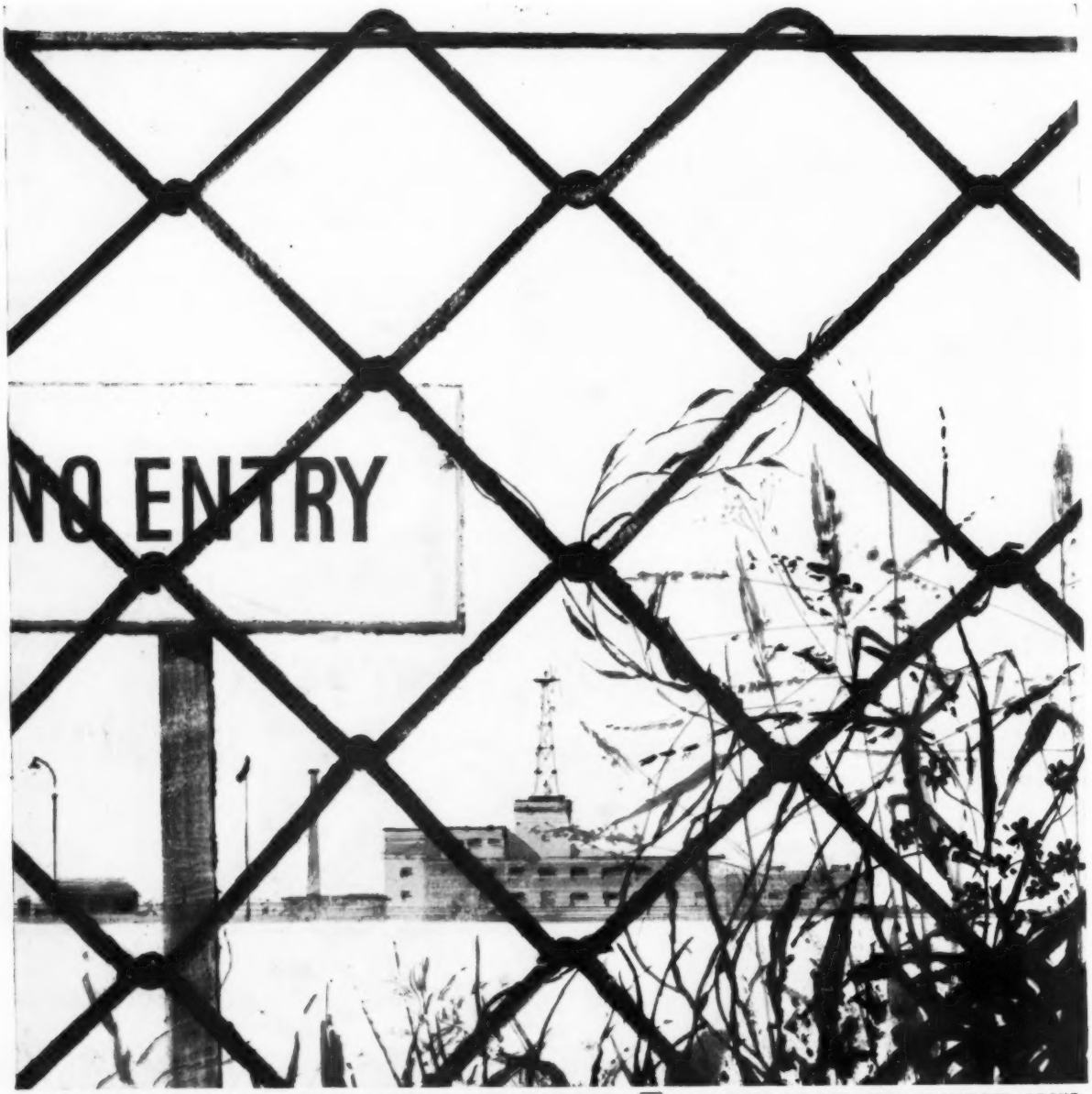

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RP 12 *for records in seconds*

RP 35 *for 50% more paper*

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'Kodak' RP.12 Print-Out Recording Paper, which produces a visible image in a few seconds, without processing, and

'Kodak' RP. 35 High-Speed Thin-Base Recording Paper, which combines the excellent photographic characteristics of 'Kodak' RP. 30 paper with a thinner base, allowing 50% more paper to be loaded into the recording instrument.

Full details of these new recording materials will be sent on request.

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P.3430

another German research reactor went critical. This reactor is fuelled with elements containing enriched uranium which have been fabricated by a highly efficient extrusion process.

We have studied known facts about the processing of enriched material and extrusion and developed technologies which led to successful industrial production of co-extruded elements.

Co-extruded matrix fuel elements too, therefore, will be an integral part of our production line in nuclear fuels.

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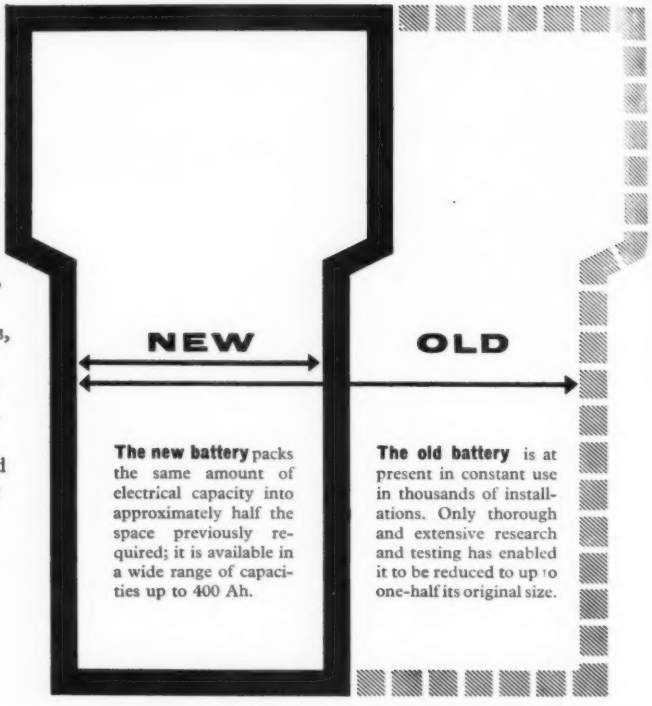
BATTERY SPACE REDUCED BY HALF

WITH THE NEW TUDOR HIGH PERFORMANCE STATIONARY CELL

Savings of up to 50% in the space required for a stationary battery are made with the introduction of a new Tudor cell. A high performance sealed cell with Planté positive plates and pasted grid negative plates, separated by ribbed diaphragms of microporous Porvic, it is specially designed for trickle-charge operation.
It is therefore the ideal cell for all stand-by applications, including emergency lighting in hospitals, cinemas, theatres and public buildings of all kinds, and auxiliary duties in both nuclear and conventional power stations.
The design of the cell results in a lower internal resistance and therefore provides a very much improved high rate performance, making it eminently suitable for switch-operating duties where high rates of discharge are involved.
With the great reduction of space required, and the renowned reliability and long life of its predecessors, this new Tudor high performance cell marks a great step forward in stationary battery design.

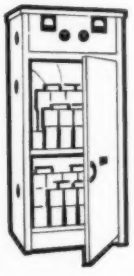


The new battery packs the same amount of electrical capacity into approximately half the space previously required; it is available in a wide range of capacities up to 400 Ah.

The old battery is at present in constant use in thousands of installations. Only thorough and extensive research and testing has enabled it to be reduced to up to one-half its original size.

THE IMPROVED SAFETYLYTE EMERGENCY LIGHTING EQUIPMENT

Tudor Safetylyte equipments are now being fitted with the new stationary cell. Charge and control cubicles are of improved design – the larger equipments being of folded sheet steel, and the smaller specially constructed for wall-mounting, employing automatic mercury relay in place of a contactor.



THE NEW SWITCH-TRIPPING EQUIPMENT

Tudor switch-tripping units will in future be fitted with the new cell. The cubicles have also been redesigned, and are available in folded sheet steel or wooden cabinet construction. The charger can now be used for both trickle and quick charging.

T 173A

Tudor TUDOR BATTERIES

THE D.P. BATTERY CO. LTD, MAKERS OF KATHANODE AND TUDOR BATTERIES, BAKEWELL, DERBYSHIRE. TEL BAKEWELL 581-5

SHAFT-READY pinions off the shelf

To make their **STOCK CHAIN DRIVES** even easier to install, **RENOLD CHAINS LIMITED** now offer a range of **64 STOCK PINIONS READY BORED AND KEYWAYED** (BS taper keyways) **FOR STANDARD SHAFT SIZES.** These provide :—

- ***THE CHEAPEST METHOD OF ATTACHING PINIONS TO SHAFTS***
- ***POSITIVE LOCATION ON SHAFT AND QUICK SIMPLE ASSEMBLY BY STANDARD KEY***

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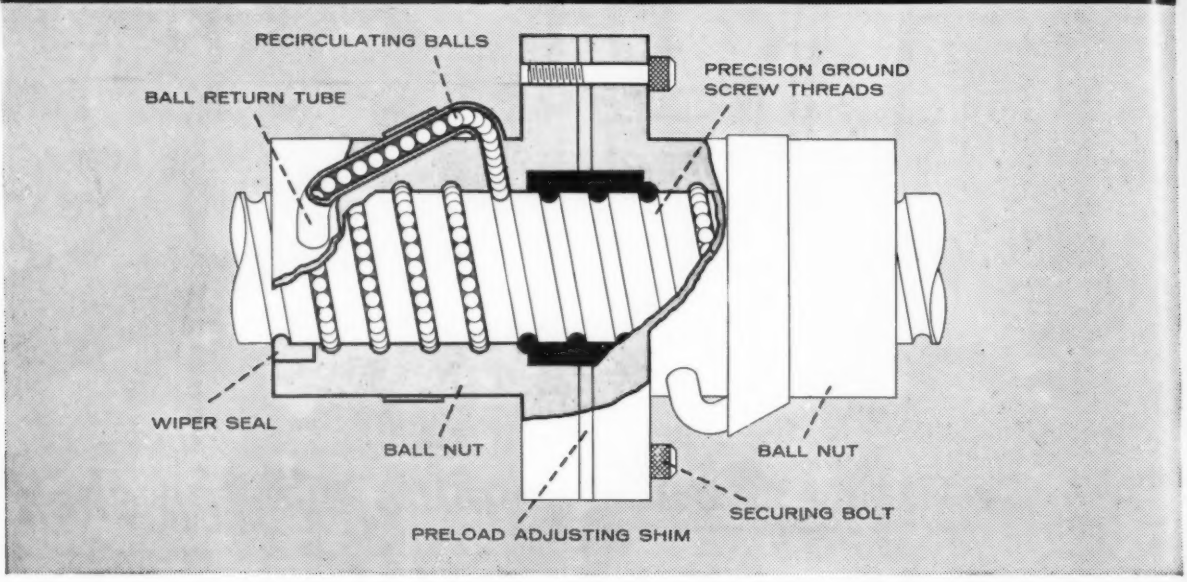
Beaver pre-loaded ball screws, up to 95% efficient, operate at -52°C to over 400°C with no backlash...



...ANOTHER ENGINEERING ADVANCE FROM BRISTOL SIDDELEY

Bristol Siddeley Engines Limited produce Beaver* pre-loaded ball screws. These ball screws achieve a minimum efficiency of 90% and they can operate within a temperature range of −52° C to 400° C without lubrication, and up to 170° C when lubricated.

Machined and ground to the highest standards of precision engineering Beaver pre-loaded ball screws greatly increase transmission efficiency. They reduce the power required for actuation by as much as 80%, when converting rotary drive into linear output or force input into torque output. By eliminating backlash, with pre-loading, they give precise control over very small increments of motion and a high response frequency. And when compared to conventional screw mechanisms, they provide a predictable operating life which is much longer, require much less maintenance and give more trouble-free operation.

Basic design application analysis

Bristol Siddeley engineers make an exhaustive analysis of each specification. And each unit is specially designed for its particular application. Beaver ball screws are made automatically reversible or with controlled "no-back," with multiple or single circuits. Beaver pre-loaded ball screws have been proved as the most efficient method of converting rotary into linear thrust in over 2,700 engineering applications in many branches of industry. They have been designed already with rated operating load capacities of 370,000 lb (825,000 lb maximum static load) but the maximum potential operating load is, in most cases, limited only by the requirement.

Bristol Siddeley Beaver ball splines have been developed to eliminate the disadvantages of conventional splines. The designs are very effective in minimising friction, particularly when high torsional and bending loads are imposed during linear movement.

** Complete technical and manufacturing co-operation with Beaver Precision Products Inc., Detroit.*

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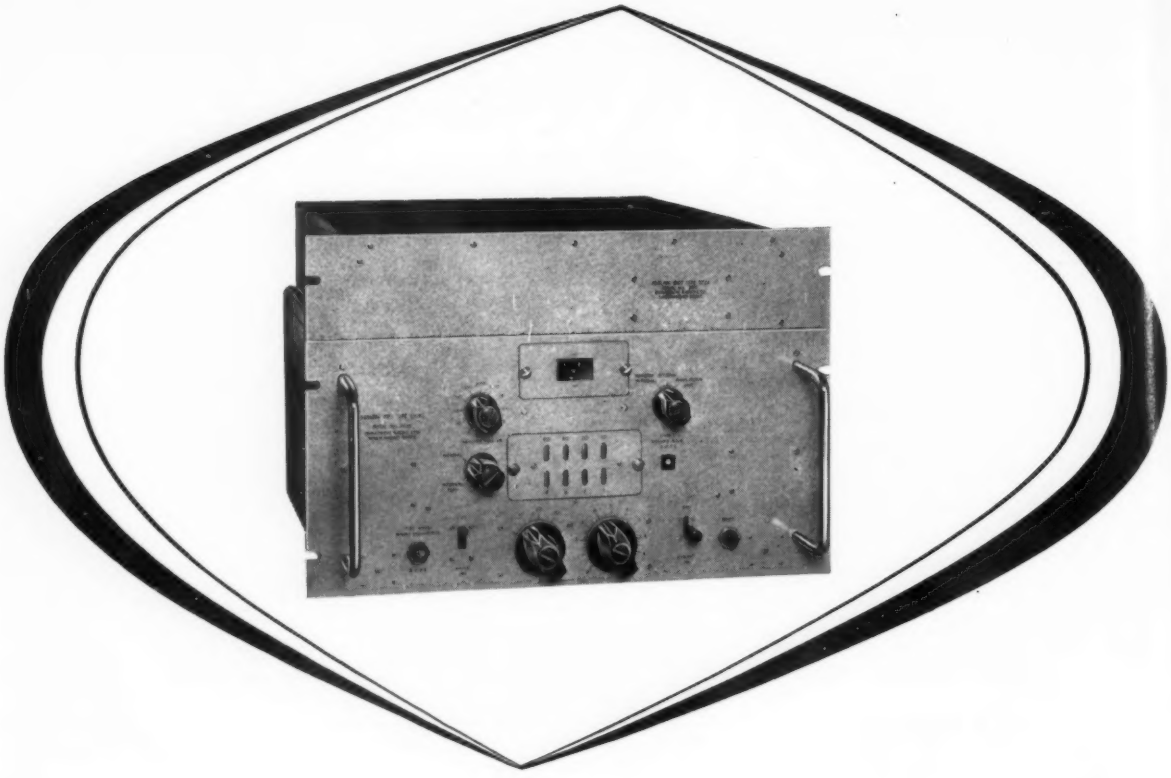

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This instrument counts random or regular electrical impulses of amplitude greater than a pre-determined value between ±5 and ±50 volts. Built-in cooling unit incorporated.

SPECIFICATION:

Pulse input: Positive, 0.25μs minimum duration.

Discriminator: 5v-50v.

Resolving Time ('Paralysis off'): 1.5μs.

Paralysis Times: Switch Selection 5, 10, 20, 50, 100, 200, 500μs; 1, 2, 5, 10 milliseconds.

Speed: This is limited by mechanical register to 2,500 per second, but may be improved by the use of an extended high speed register.

Stability: Mains variation of ±10% have no effect on the working of the equipment.

Made in conjuction with and under Atomic Energy Research Establishment licence.

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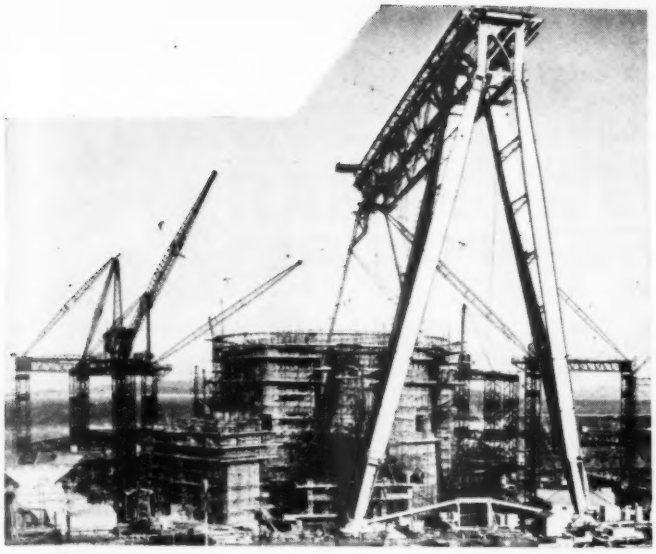
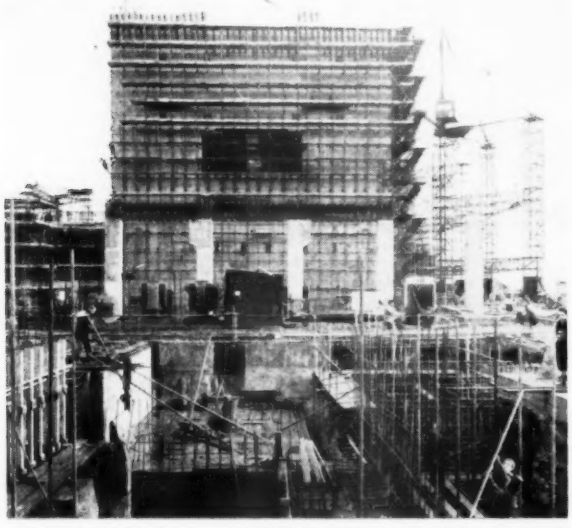
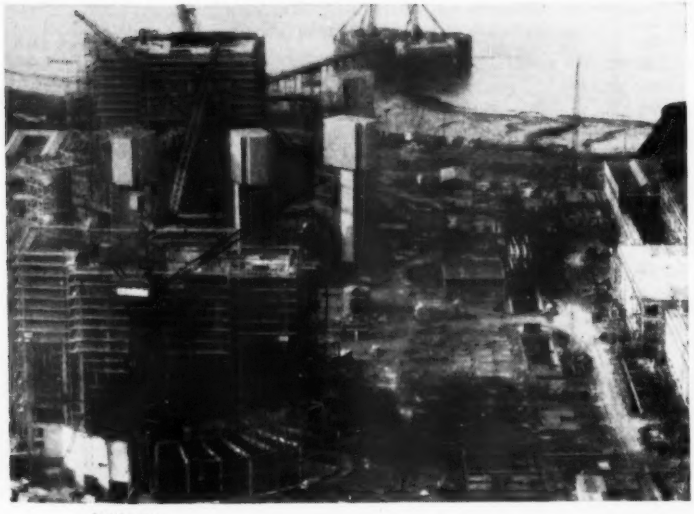


Hunterston



Hinkley Point



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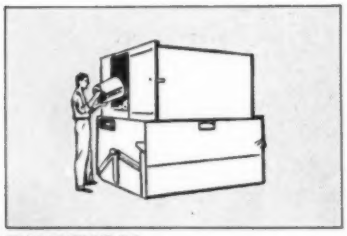
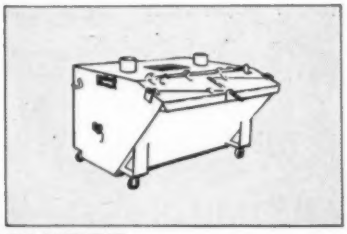
is the **NEW** *method of waste collection and disposal by*

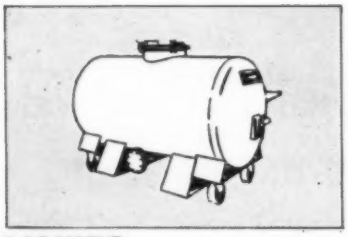
DEMPSTER DUMPSTER SYSTEMS



RUBBISH



SLUDGE



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For large scale bulk collection and movement, the Dempster "Dinosaur" is capable of picking up or setting down, off-loading onto raised wharf or tipping to empty, bodies of up to 40 cu. yards capacity.

Dempster systems are adaptable to meet every waste disposal problem and are suitable for many process materials handling applications.

If you have a waste handling problem or are collecting by conventional methods why not ask for a survey to be made without obligation? Further information on request—films also available by arrangement.

Manufactured under licence in U.K. by:—

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'DURIUM'
TIPPED MASONRY DRILLS

So famous have these amazing drills become that the name DURIUM tends to be used for any drill of its general type. *Don't be misled by this.* DURIUM means the special New Process, almost diamond-hard, carbide tip developed and made only by the Rawlplug Company. *No* other drill is a genuine Durium. DURIUM Drills give really sensational cutting performances in brick, tile, cement, slate, etc. They are silent in operation and have a quite exceptional long-service capacity for withstanding the abrasive action of masonry that so quickly ruins ordinary drills. Another exclusive feature of Durium Drills is their patented rapid-helix flute, which forces out spoil and prevents clogging. Only a Durium Drill—a *genuine* Rawlplug Durium—gives such life and service. First resharpening is FREE!

For use in Wheelbrace or slow speed electric drill

17 sizes 5/32" to 1" cutting diameter and **11** *long series* ¼" to 1" cutting diameter for up to 16" drilling length.

'DURIUM' TIPPED HAMMER DRILLS

For percussion drilling in hard materials such as Granite, Blue Bricks, Concrete etc., Durium Hammer Drills have a very much longer life than ordinary percussion drills. They can be used in most electric Hammers and some type of Pneumatic Hammers. 13 sizes from 7/16" nominal drill diameter to 1¾".

'DURIUM' TIPPED GLASS DRILLS

For use in glass, china, vitrolite, pottery, etc. Can be used in a wheelbrace or slow speed electric drill. 9 sizes from ¼" to ½" cutting diameter.

'VIBROTO'
HARD TIPPED DRILLS FOR VIBRATORY DRILLING

Vibroto Drills are specially manufactured for use with the Vibroto Drilling Machine, —a high efficiency power tool which allows of two vibratory actions (Light Rapid and Heavy Slow), and also a rotary action for use with standard Durium masonry Drills or ordinary Twist Drills. With their special cutting angle metallic carbide tips, and the high grade steel shanks heat-treated to withstand abrasion, Vibroto Drills put up spectacular performances in the drilling of concrete and other hard materials. *Demonstrations* can be carried out by Rawlplug Technical Representatives anywhere in the British Isles.

10 sizes 5/32" up to 15/32" cutting diameter.

'RAWLCRETE'
TUNGSTEN CARBIDE TIPPED (ROTARY) CONCRETE DRILLS

These drills are designed for hole boring in concrete, hard brickwork and tiles with portable rotary action tools. They have from four to six cutting edges (depending on size) and if one should be damaged the remainder will go on cutting. Spoil is automatically carried away through the cored shank and ejected via the slot.

EXTENSION TYPE DRILLS ANY DEPTH

By adding extension rods to the Extension Type Rawlcrete Drill, any depth of hole can be drilled.

26 sizes ¼" up to 2" cutting diameter.

RAWLPLUG FIXING DEVICES AND TOOLS FOR SPEED AND RELIABILITY

WRITE NOW for illustrated literature describing fully these and other Rawlplug high performance drills and power tools.

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THE RAWLPLUG COMPANY LTD.
CROMWELL ROAD, LONDON, S.W.7.
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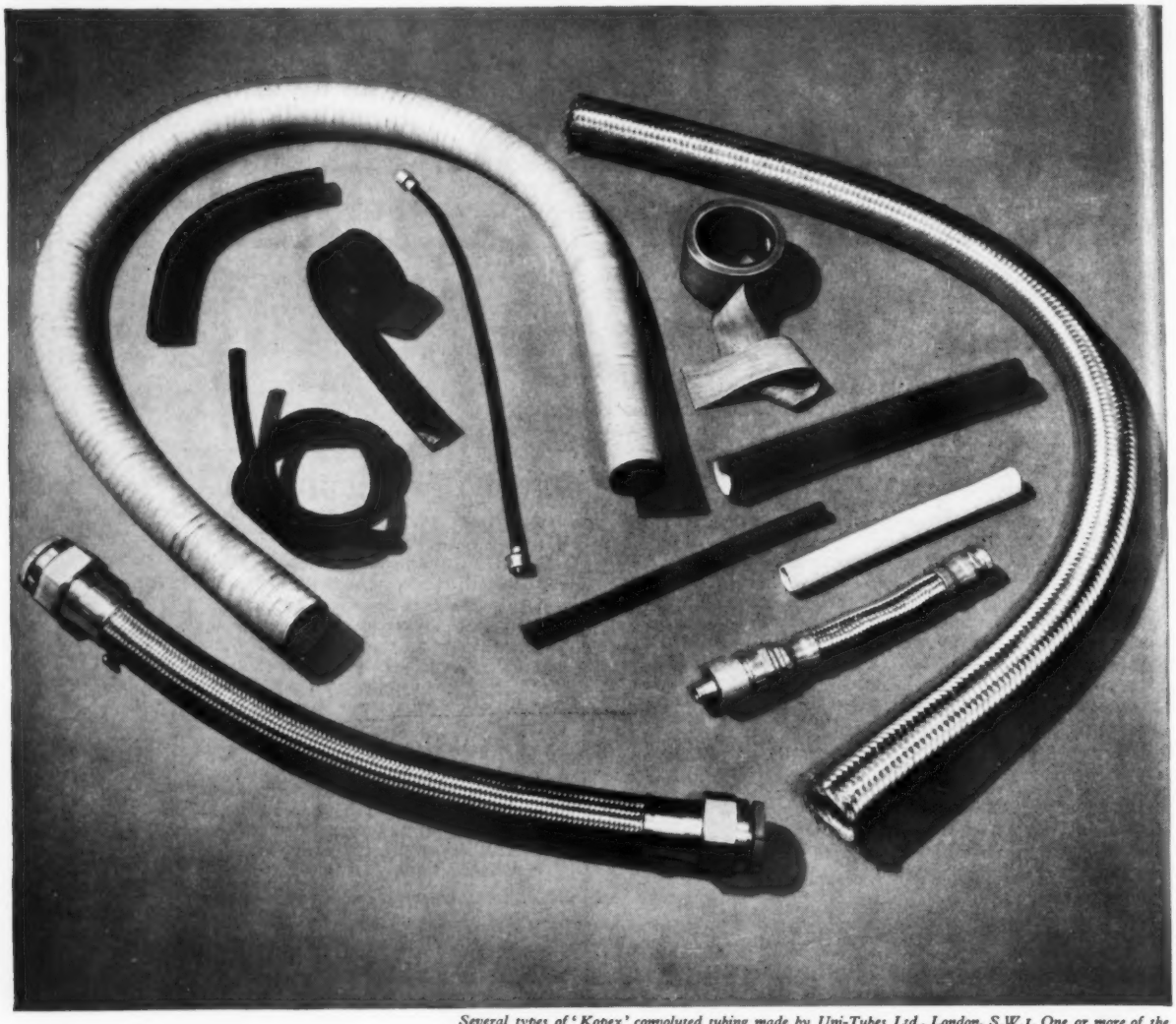
'FLUON' INCREASES PRODUCTION IN THE CHEMICAL INDUSTRY



Several types of 'Kopex' convoluted tubing made by Uni-Tubes Ltd., London, S.W.1. One or more of the component layers of the tubing are made from either 'Fluon' tape or 'Fluon' impregnated Fibreglass tape.

Why 'Fluon' was chosen in the manufacture of 'Kopex' convoluted tubing

ONE of the many types of 'Kopex' convoluted tubing made by Uni-Tubes Limited has to be corrosion and abrasion resistant. It must not be affected either by high or low temperatures. It must have a low coefficient of friction so as to facilitate threading with cables.

To ensure that it offers all these advantages, the manufacturers have used 'Fluon' tape or Fibreglass tape impregnated with 'Fluon' for one or more of the component layers of tubing.

This tubing is used, among other things, to protect electrical harness in aircraft against de-icing fluids. It is also used as electrical cable conduit; hose for carrying non-inflammable hydraulic fluids, high temperature lubricating oils and most other corrosive fluids; for steam, missile fuel, and oxygen lines.

'Fluon' which is a tough, flexible material, has a remarkable range of properties:— a working temperature range from +250°C. down to at least liquid nitrogen temperatures; resistance to virtually all forms of chemical attack; the lowest coefficients of friction of any solid; and the best dielectric properties.

'FLUON'

'Fluon' is the registered trade mark for the polytetrafluoroethylene manufactured by I.C.I.

ICI

IMPERIAL CHEMICAL INDUSTRIES LIMITED · LONDON S.W.1

PTFE

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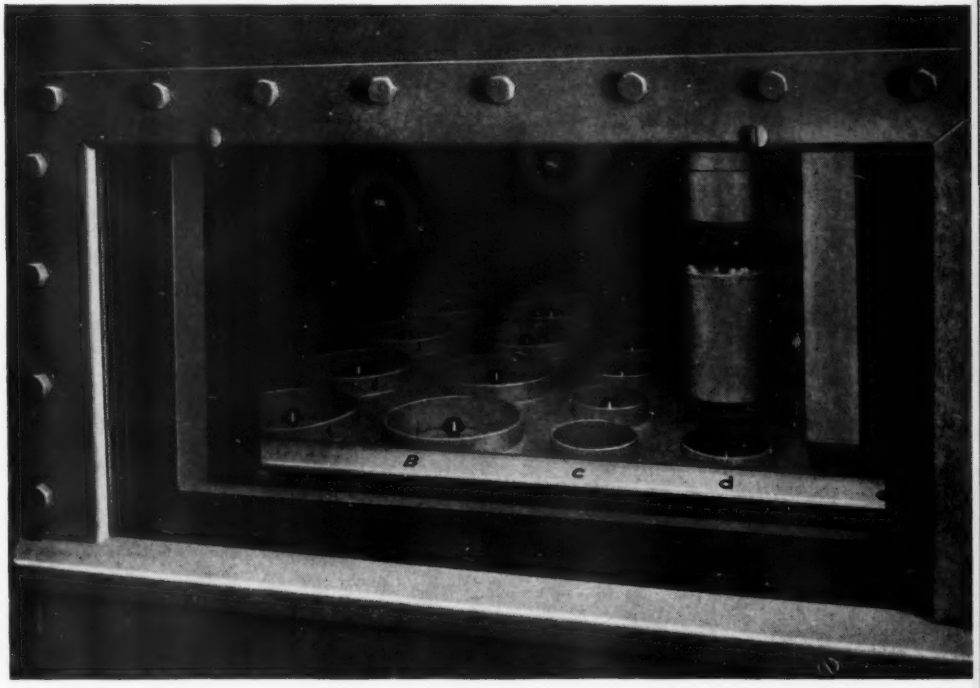
against Radio-active Radiation

There are 10 types available with varying lead content and in densities from 2.53 to 6.20. Among those there are also several stabilized types which will not become brown even under exposure to high radiation doses. The great number of glass types permits good adaptation of the thickness of the windows to that of the protective walls. Depending on glass type it is possible to produce blocks in sizes up to 1,3 m at thicknesses from 15 to 30 cm.



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made of best optical glass in untempered and tempered quality. Even large windows can be tempered.

Cylindrical Blocks of Lead Glass for Cerenkov-Counters
of high refractive optical glasses, especially free from colour.

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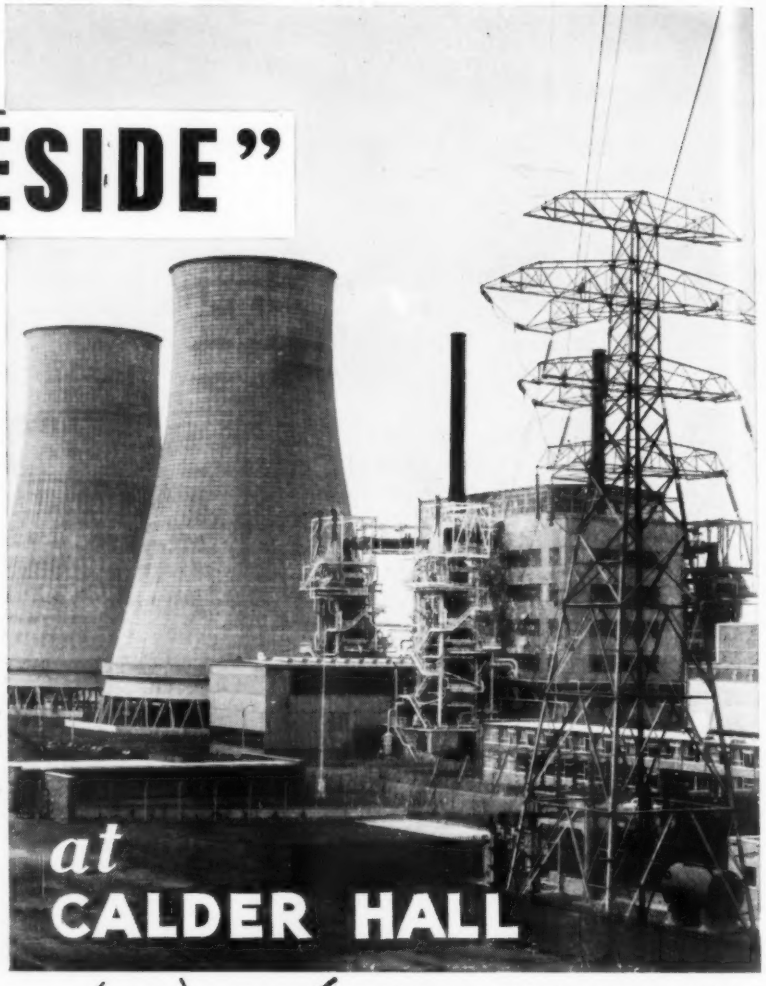

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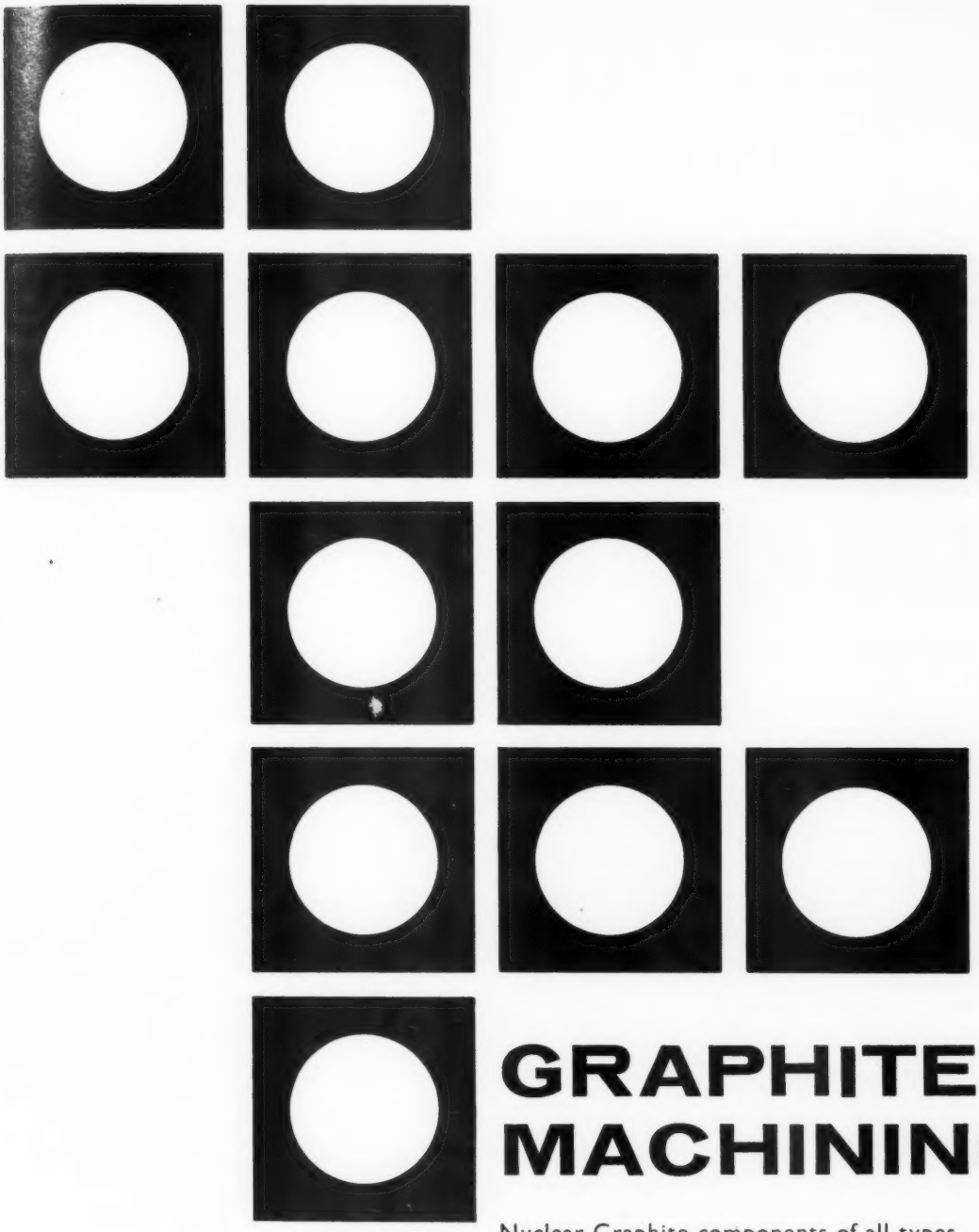

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Bulk deliveries now in progress to Hunterston and other Nuclear Power stations.

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General Buildings, Aldwych, London, W.C.2 (*Telephone:* HOLborn 1985)
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Test its STRENGTH

NEWTHERM is unusually strong and rigid—a feature of special importance in the larger, more vulnerable sections. Put a sample section or slab on part of your plant and *prove for yourself* its outstanding ability to withstand impact and water damage. See how it withstands rough handling in transit and erection, minimising breakage in shipment and erection by unskilled labour at the most remote sites.

Test its MOISTURE RESISTANCE

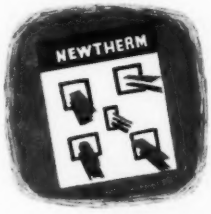
Even totally immersed in water, NEWTHERM retains much of its strength and rigidity. It does not become deformed when in contact with water, thus work-in-progress need not be covered. Especially on contracts where weather conditions would delay the application of insulation—NEWTHERM is the material to use.

Test its LIGHTNESS

Unusually light for such a high-efficiency material, NEWTHERM compares favourably in this respect with other insulants far inferior in strength. That means easier handling and fewer breakages—even the largest section is easily carried in one hand.

Test its EASE OF APPLICATION

Undoubtedly, NEWTHERM is one of the easiest of materials to apply. It is supplied in plastic form and in a wide range of standard-sized sections and slabs, smoothly finished and straight edged for immediate fitting. The finished job is very neat, with minimum joints, and appliers particularly appreciate the handleability of the material - especially in difficult situations.



READ ALL ABOUT NEWTHERM

in a specially prepared booklet. Sizes, compressive strength, thermal conductivity,—this and much more useful information can be on file if you write for your copy now, to the sole manufacturers Newalls Insulation Co. Ltd.

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***NEWTHERM** calcium silicate insulation*

. . . for temperatures up to 1400°F.

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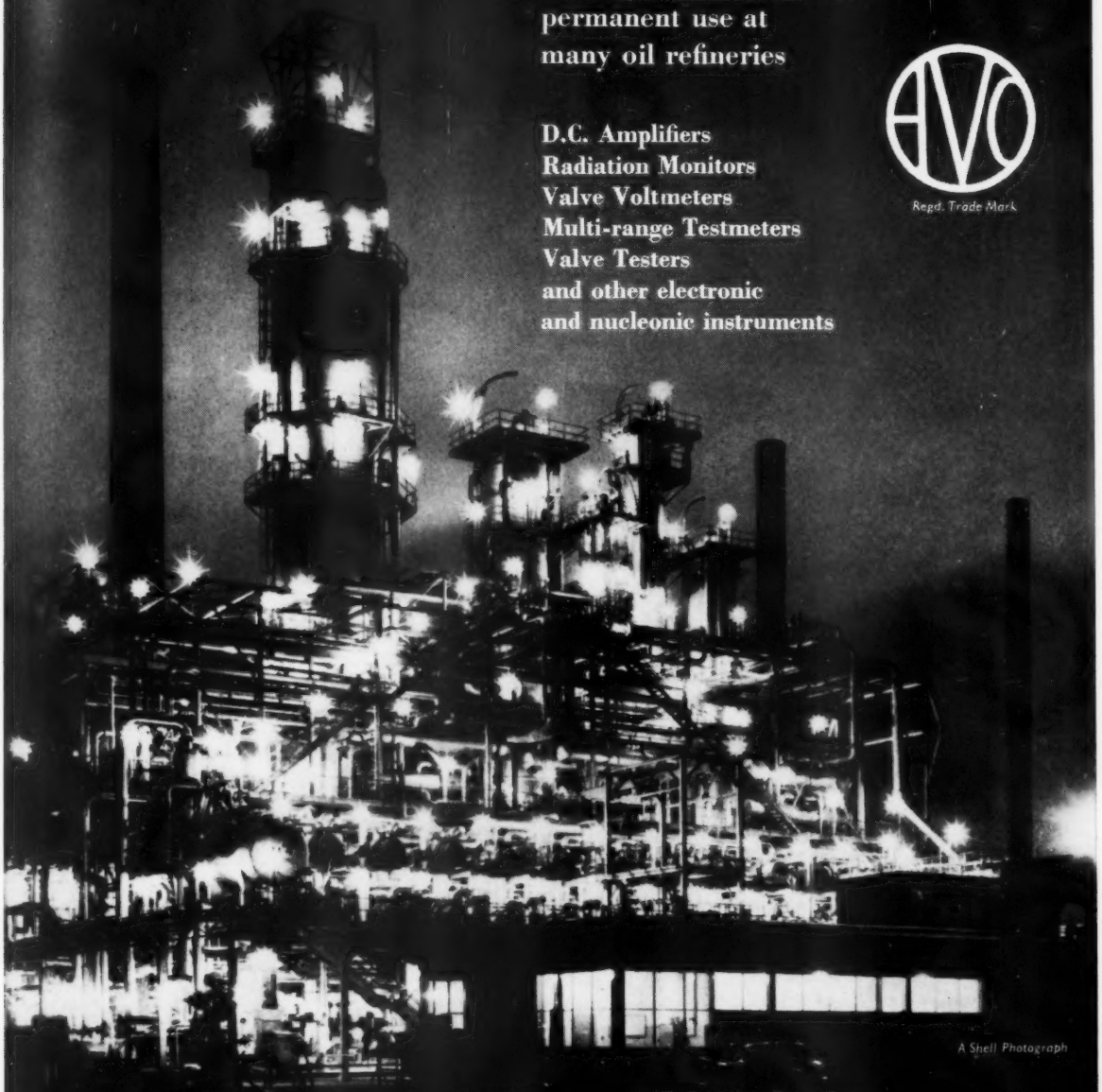

A Shell Photograph

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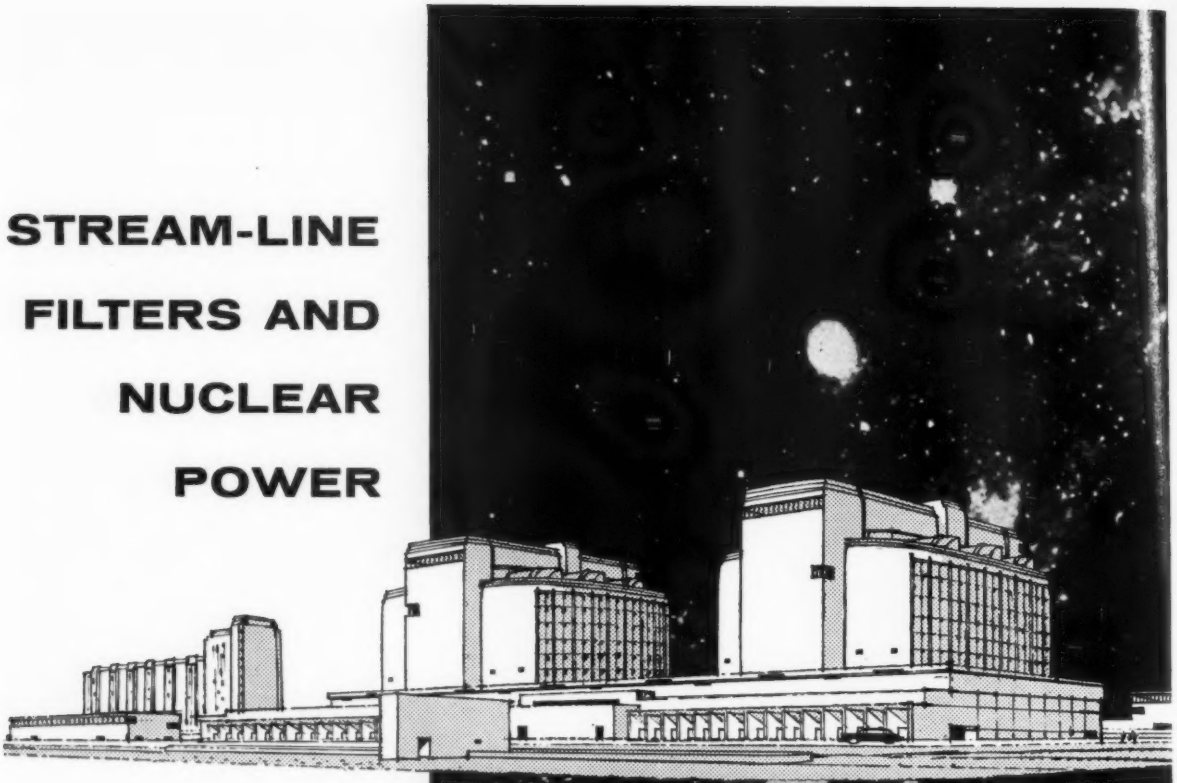
G22

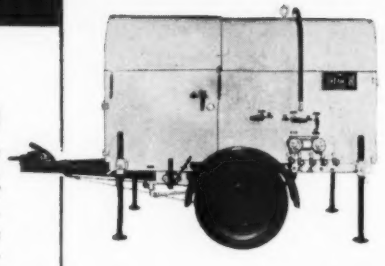
STREAM-LINE FILTERS AND NUCLEAR POWER



The security of oil-immersed circuit breakers or transformers depends on the condition of the oil. In Stream-Line filters the engineer has at his disposal equipment specially designed for the complete removal of contamination in insulating oil and which meets the most stringent requirements. That's why Stream-Line filters have been specified for Chapel Cross and Berkeley, and are in wide use throughout the U.K.A.E.A. A single passage through a Stream-Line filter ensures the elimination of solid impurities, even the finest colloidal carbon; dehydration, including the removal of dissolved water, and de-aeration, including the removal of dissolved gases. A dielectric strength far above that specified for the highest quality new oil is achieved by a standard Stream-Line filter. Our research and development department will be glad to answer your queries. Write for Catalogue W.1031.

A WORD ABOUT HIGH VACUUM

Stream-Line filters designed to operate under high vacuum can be supplied. Details are available on request of models yielding remarkable performances. For most requirements the standard Stream-Line filter gives precisely the service demanded.



A fully mobile Stream-Line filter.

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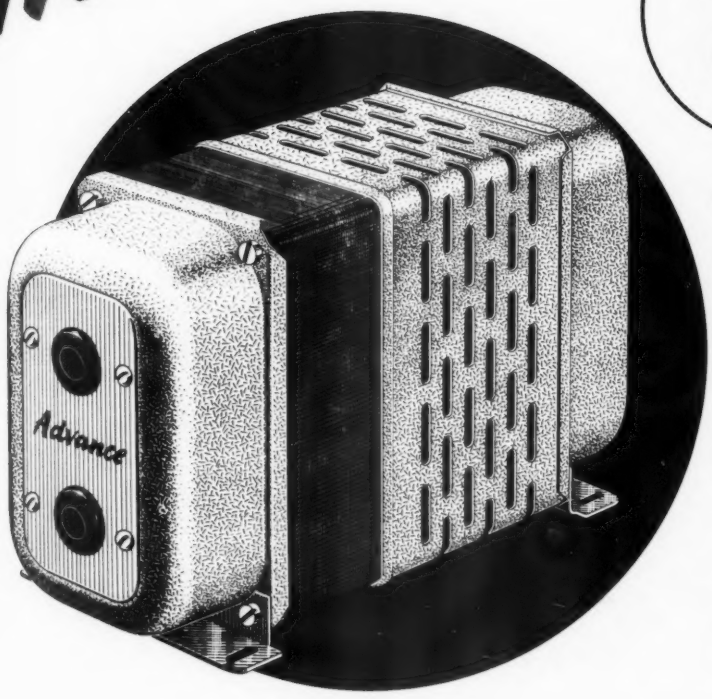
More WATTS PER £ lb



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Take the best in Constant Voltage Transformer design and practice . . . maintain all those features proven by years "in the field" . . . . add still greater efficiency . . . . reduce size and weight . . . . and then drastically cut the cost — and you have the NEW CV Series.

Models now available with output capacities of 25, 50, 75 and 100 watts and range of outputs from 6 to 240 volts — all providing assured output voltage regulation within ±1% for input variations of up to ±15%

- **WEIGHT REDUCED by over 25%**
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- **WILL OPERATE CONTINUOUSLY AT AMBIENT TEMPERATURES from −10 to +50°C.**

CONSTANT VOLTAGE TRANSFORMERS

They are **SMALLER-LIGHTER** *and* **COST LESS!**

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	MODEL CV.25/E	MODEL MT.281/E
Input Voltage	190-260V	190-260V
Output Voltage	6V	6V
Output Capacity	25W	25W
Dimensions	5½"×3 3/16"×4¼"	7"×5½"×4¼"
Weight	5lb	7lb
	PRICE £6.5.0	PRICE £8.0.0

Full details in Folder N.63 available on request

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GD80

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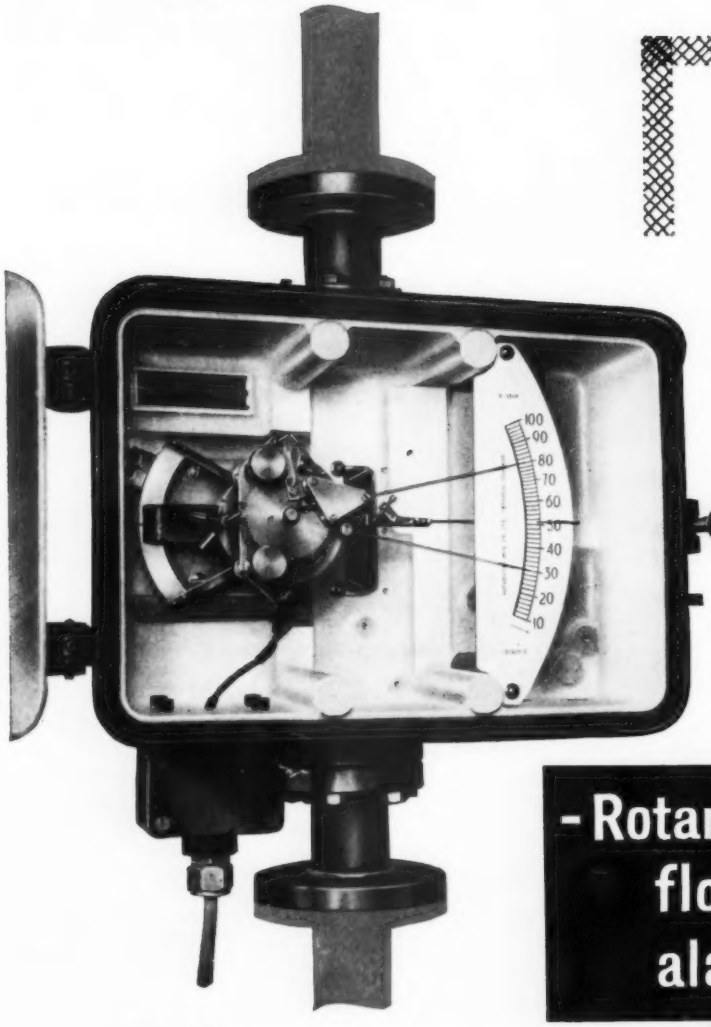
for SAFETY in your pipeline

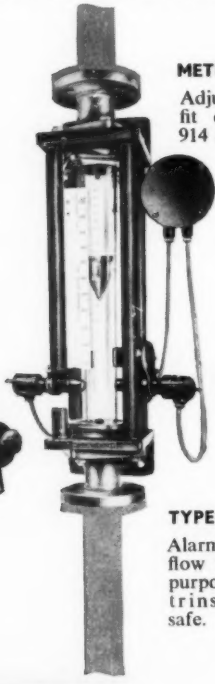


TYPE 500A

Electric or pneumatic signal, fully adjustable for liquids or gases.

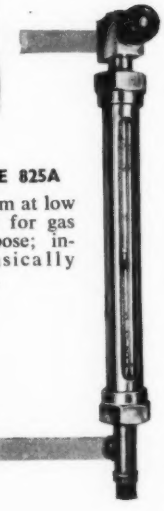
METRIC SERIES

Adjustable alarm to fit on size 907 and 914 Rotameters. When float interrupts light beam, electronic relay is operated.



TYPE 825A

Alarm at low flow for gas purpose; intrinsically safe.



- Rotameter flow alarms

TYPE 750

Fixed alarm, non-indicating, electric signal; can be certified flameproof.

Where a change of liquid or gas flow rate is dangerous then one of these Rotameter flow alarms can be used to provoke attention. Electric or Pneumatic signals provide visual or audible alarm.
Type 500A has been specially designed to indicate high pressure gas flows in atomic reactor coolant circuits. It has two alarm points which are freely adjustable and which have a minimum differential of about 10% full scale. This instrument is also suitable for liquid flow.

ROTAMETER

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FLOW-DENSITY-LEVEL

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They were vertical Glandless pumps and there's reasoning behind the choice.

The simple design having only one moving part and no close clearances ensures non-stop service and long life.

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These pumps are self-priming and can be located above liquid level.

if you want dependability—
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RADIATION SHIELDING WINDOWS

Measuring up to 4 ft. 6 inches x 3 ft. x 10 inches thick or up to 12 inches thick for slightly smaller sizes. Available as polished glass blocks or as complete composite windows fully framed for insertion in the shielding wall. A range of densities is available in both stabilised and unstabilised glasses.

Our Technical Advisory and Design Service exists to help you solve your Radiation Shielding Window problems. Please write to us for full details.

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Pilkington Brothers Limited
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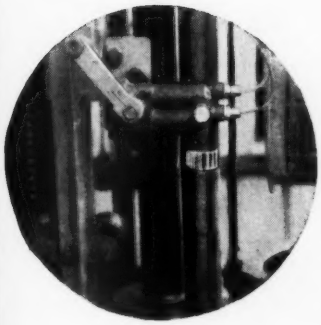

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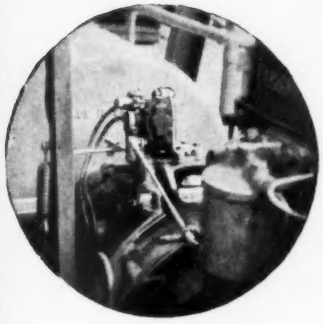

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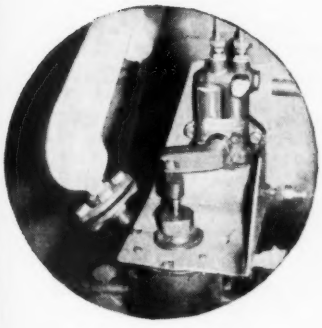

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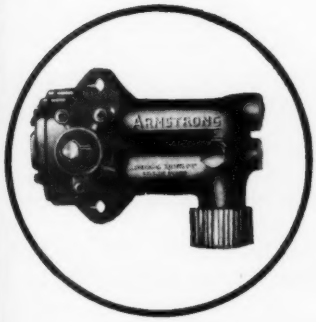

Now you can buy control in a package!

To install first-class hydraulic circuits with the Armstrong "Off-the-Shelf" Actuator is to use *the easiest and most economical means in the world.*

You can select a combination of the various types of Armstrong Actuator units to suit your individual requirements. Accurate assembly requires only elementary engineering knowledge, simple instructions are provided and stock embodiment items supplied. An Armstrong Actuator does away with the need for heavy or complicated linkages and gives none of the troubles that tend to crop up with links, levers or cams. Once installed and charged, it will function for as long as the machine or structure in which it is embodied—smoothly and efficiently. This bold new conception of hydraulic control has behind it the vast experience gained by the Armstrong Patents Company Limited of Beverley. They alone, because of their unique position in the field of hydraulic engineering, are able to offer Actuators of this quality at the price.

Armstrong "Off-the-Shelf" Actuators—power or manually operated—put so many possibilities "within your reach" that early investigation is advised. Ask for leaflet APL 51/21.

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AIRMEC INSTRUMENTATION

keeps in step with nucleonic needs

MONITORS

RADIATION MONITOR *Type 1021 B*

- ★ **SAFEGUARDS against contamination.**
- ★ **TRACES radio-active material in chemical analytic processes.**
- ★ **MEASURES contamination of any resulting effluent.**

Designed in conjunction with A.E.R.E. Harwell, this instrument is probably the most widely used general purpose monitor in the world. It has been PROVED by years of user experience to be the most accurate and reliable equipment of its type.

The Radiation Monitor consists of a mains operated Indicator Unit together with a Beta Gamma or Alpha Probe Unit. Indication is provided visually by means of a meter which is calibrated in counts per second, and audibly by means of a loudspeaker. A socket on the front panel is also provided to enable the output to be fed to a scaling unit.

Write for descriptive leaflet No. 26D giving full details.

RADIATION MONITOR *Type 255*

- ★ **Transistorised, battery operated, portable.**
- ★ **Laboratory accuracy under field conditions.**
- ★ **Wide range of probes and accessories available.**

Airmec are proud to be the first to announce a fully transistorised monitor which combines laboratory accuracy with complete portability. The uses include:

1. Checking t e presence and amount of radio-active contamination in laboratories and workshops.
2. Checking atmosphere 'fall-out' and contamination of food, animals, crops, milk and water supplies, etc.
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4. Tracing the whereabouts of radio-active areas and making accurate assays of samples in geological surveys.
5. Tracing lost samples of radio-active materials both in buildings and out.

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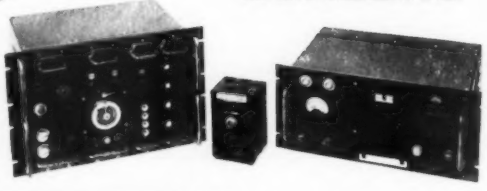
SCALERS



GENERAL PURPOSE COUNTER *Type 1339 A*

- ★ **Designed and developed in conjunction with U.K.A.E.R.E.**
- ★ **Provides comprehensive scaling facilities for all types of Geiger Scintillation Counters.**
- ★ **Incorporates stabilised E.H.T. supplies.**
- ★ **Fitted with automatic timing control.**

This equipment is built on a unit basis and provides very comprehensive scaling facilities for all types of accurate assay work. It consists of two main units — a Power Unit and a Scaling Unit — together with a number of optional sub-units. These include a Quenching Unit, a High Speed Scaling Unit, an Amplifier/Discriminator Unit, a Paralysis Unit and a Timing Unit.

Full details are given in descriptive leaflet No. 185

Airmec

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the best heat exchangers use

SWIRLYFLO

"SWIRLYFLO" TUBING, designed and developed for use in our boilers and heaters, has proved to have greater efficiency, in transferring heat over any given length, than any other tube.

TUBES

Increased efficiency is obtained through the specially designed spiral twist in the tube, the hot gases passing through them are jostled and bounced against the walls, extracting the maximum amount of heat to be used as well as spent energy. For given results less tube length is required, as a six foot length of Swirlyflo tube does the work of a ten foot length of plain tube. All round advantages are obtained—thicker tube walls giving a 20% longer tube life—shorter tubes mean smaller boilers and saving in floor space.

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Swirlyflo Tubes

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Telegrams: Swirlyflo, Bracknell, Telex;
Telex: 84130

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in connection with high pressure

ERMETO FLEXIBLE HOSES can be used with a wide range of fluids and are increasingly employed where rigid pipes would be impracticable. ERMETO flexible hose is available in unit lengths of up to 60 feet with single or double wire braiding, and can be supplied with an extensive range of end fittings. Technical advice and illustrated literature will gladly be supplied on request.

ERMETO **BRITISH ERMETO CORPORATION LTD**

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Rio Tinto is now able to supply

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Barrington House, 59 Gresham Street, London, E.C.2. Telephone METROPOLITAN 9101

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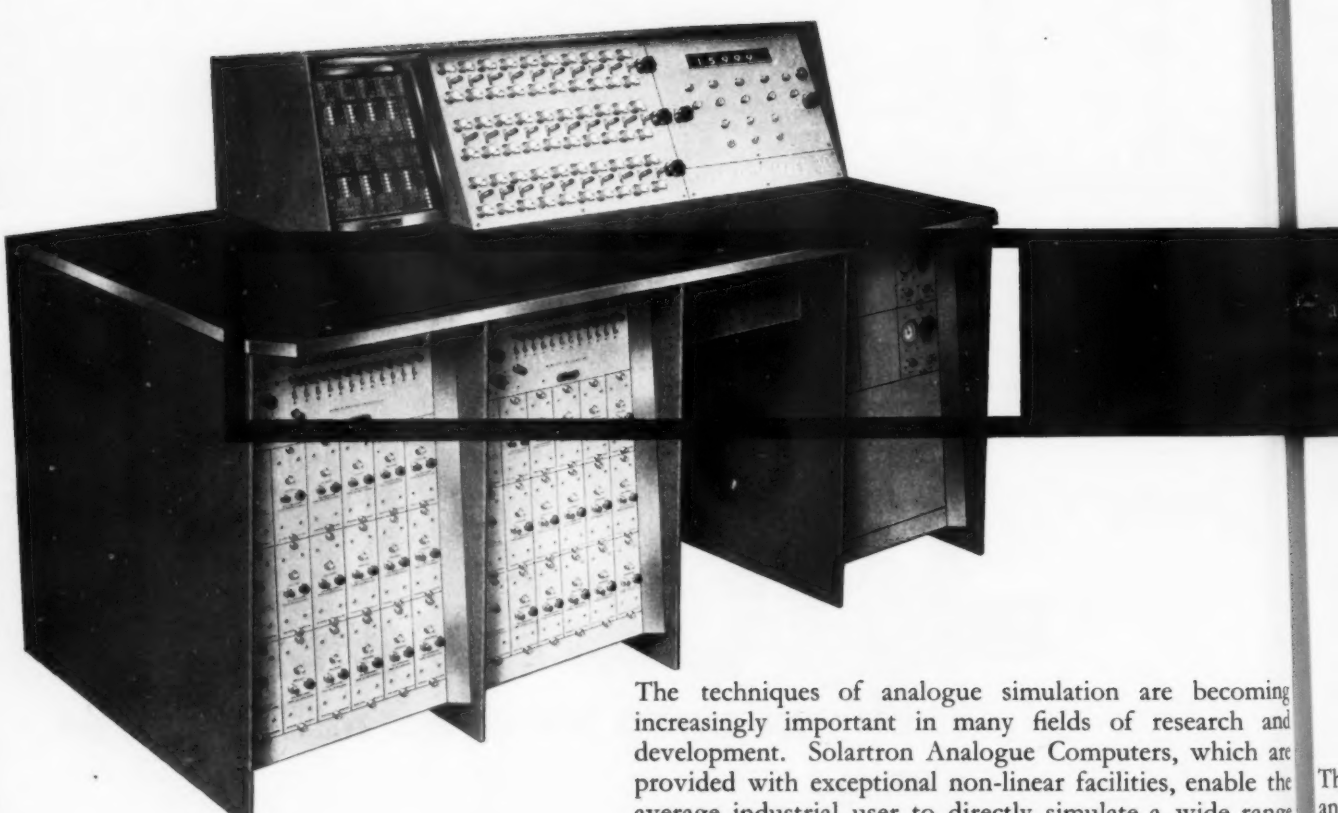
SOLARTRON

Space 30 Analogue Computer

foremost in flexibility



The techniques of analogue simulation are becoming increasingly important in many fields of research and development. Solartron Analogue Computers, which are provided with exceptional non-linear facilities, enable the average industrial user to directly simulate a wide range of physical systems without having to resort to special-purpose simulators.

The inclusion of programmed timing devices, servo multipliers and function generators, allows a great variety of non-linear and control problems to be directly simulated.

In order to assess the suitability of a particular computer for any given application, it is essential that expert advice be sought before the final specification is fixed. Accordingly, without obligation, Solartron will be pleased to provide application engineering assistance in the planning of computers to actual user requirements.

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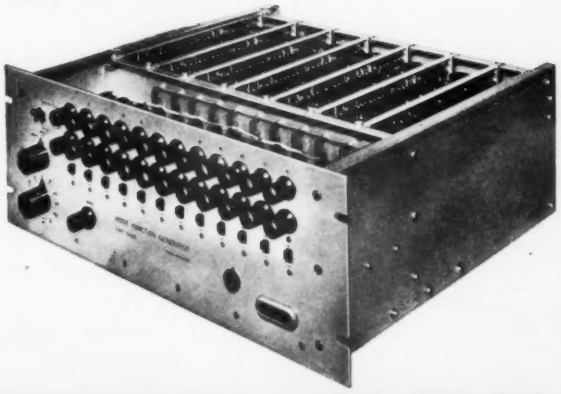
THE SOLARTRON ELECTRONIC GROUP LTD., Thames Ditton, Surrey

SOLARTRON

The Solartron Diode Function Generator is a 12-segment unit which sets a new high standard for resolving power, bandwidth and ease of operation.



Bandwidth;
DC to 100 c/s, with less than 1° of phase shift

Stability;
Long term, 0·25% or better

Segmental Drift;
Less than 100 mV

Segmental Gain Error;
Less than 0·2%

The Solartron Servo Multiplier and the Solartron Diode Function Generator open up new avenues of investigation to all users of Analogue computing equipment

Write now for literature

The Solartron Servo Multiplier is an extremely accurate general purpose potentiometric multiplier which is transistorised and employs gearless servo drive for exceptional dynamic performance.

Up to five variables may be simultaneously multiplied by one other, or up to the sixth power of a variable may be generated by this versatile unit.

Bandwidth;
DC to 10 c/s, at maximum amplitude with less than 1° of phase shift

Features;
Provision for preset function generation

Highly stable, transistorised power supply incorporated

Six-gang potentiometer assembly

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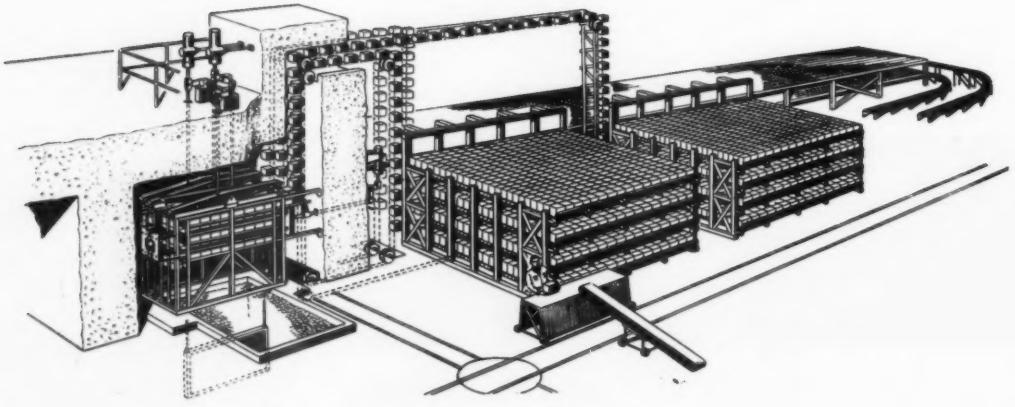
Tel. EMBerbrook 5522 Cables & Telegrams: SOLARTRON, Thames Ditton

Package Irradiation Conveyor Plant developed in co-operation with the U.K.A.E.A. by

The Owen Organisation



The resources of the Owen Organisation are co-ordinated to serve the Nuclear Industry in Design, Development and Manufacture.

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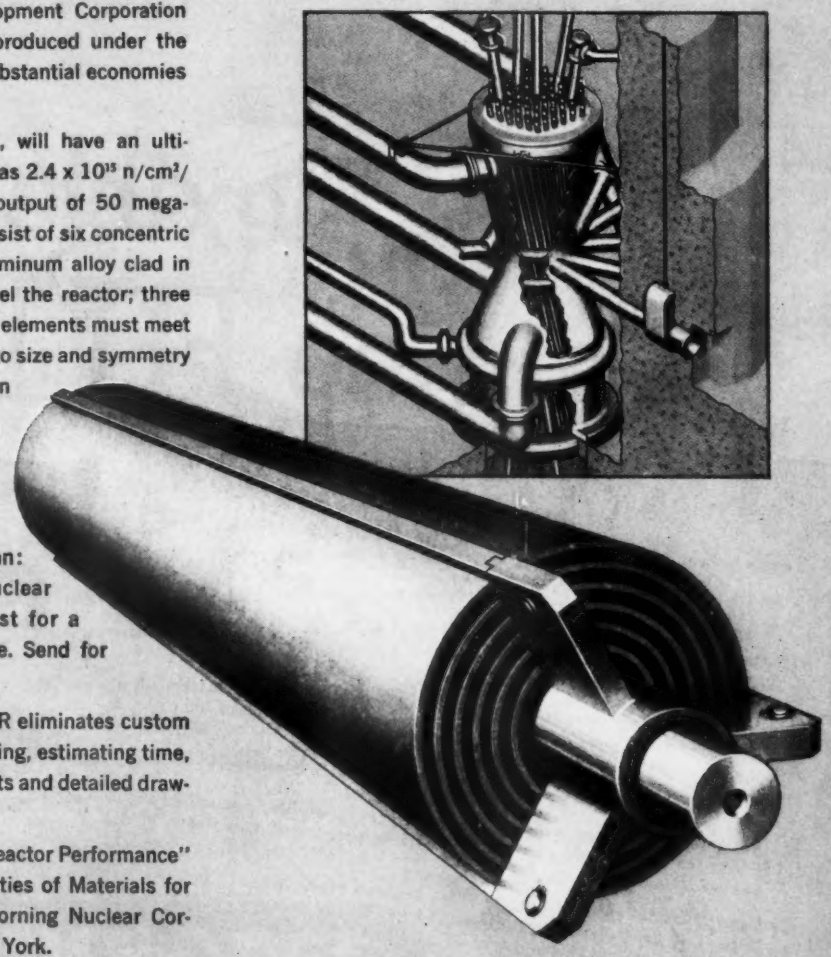
THE OWEN ORGANISATION GROUP ATOMIC ENERGY OFFICE
LIVERPOOL ROAD · WARRINGTON · Telephone WARRINGTON 35241

Europe's Highest-fluxed Reactor will be FUELED by SYLCOR

The Belgian Engineering and Test Reactor, now under construction at Centre d'Etudes pour les Application de l'Energie Nucleaire at Mol, Belgium, is a notable example of joint American-European attainments in the field of nuclear technology. The plant will be of unique and advanced design by Nuclear Development Corporation of America. Fuel elements will be produced under the SYLCOR "Package Fuel" plan with substantial economies to the Belgian government.

The new reactor, designated METR, will have an ultimate epithermal flux density as high as 2.4×10^{15} n/cm²/sec, corresponding with a thermal output of 50 megawatts. The SYLCOR fuel elements consist of six concentric tubes of 90% enriched uranium-aluminum alloy clad in aluminum. 20 such elements will fuel the reactor; three core loadings are being supplied. The elements must meet rigid dimensional tolerances both as to size and symmetry of tubes and water gaps and have been flow-tested at 35 feet per second.



Two recent SYLCOR developments warrant your study in designing or fueling nuclear power plants:

(1) The SYLCOR "Package Fuel" Plan: You obtain your allocation for nuclear material . . . SYLCOR does the rest for a fixed price which is the total charge. Send for information.

(2) Standard Fuel Elements: SYLCOR eliminates custom design, special drafting and engineering, estimating time, special tooling and testing. Data sheets and detailed drawings on four types available.

Write for "Nuclear Fuels: Key to Reactor Performance" and "Physical & Engineering Properties of Materials for Nuclear Fuel Elements." Sylvania-Corning Nuclear Corporation, Bayside, Long Island, New York.

SYLCOR

SYLVANIA–CORNING NUCLEAR CORP.

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Flexible HOSES and hose FITTINGS

Lockheed Avery flexible hoses meet most requirements for pressure or vacuum and employ a range of reusable end fittings which may, if required, be assembled to the hose on site.

The following types are standard:

Type 14 Low/Medium Pressure Hose. Sizes ¼" to 2"
Cotton braided hose, lined and covered with synthetic rubber. For working pressures of 850 to 75 p.s.i., according to size.

Type 14WR Low-Pressure/High Vacuum Hose. Sizes 1½" to 5"
This type is 'tailor made' to order. For working pressures of 200 to 100 p.s.i. according to size.

Types 75, 76, 77 and 78. High-Pressure Single Wire Braided Hose. Sizes ¼" to 2"
Choice of four different linings, to resist practically every oil, chemical, spirit or acid in ordinary industrial use. For working pressures from 4,500 to 500 p.s.i., according to size.

Type 99 High-Pressure Double Wire Braided Hose. Sizes ¼" to 2"
Lined and covered with Neoprene, high-duty construction throughout. Suitable for hydraulic fluids, diesel oil, petrol, etc. For working pressures of 5,500 to 1,000 p.s.i., according to size.

NORMAL TEMPERATURE RANGE FOR ALL HOSE –40C TO + 100C

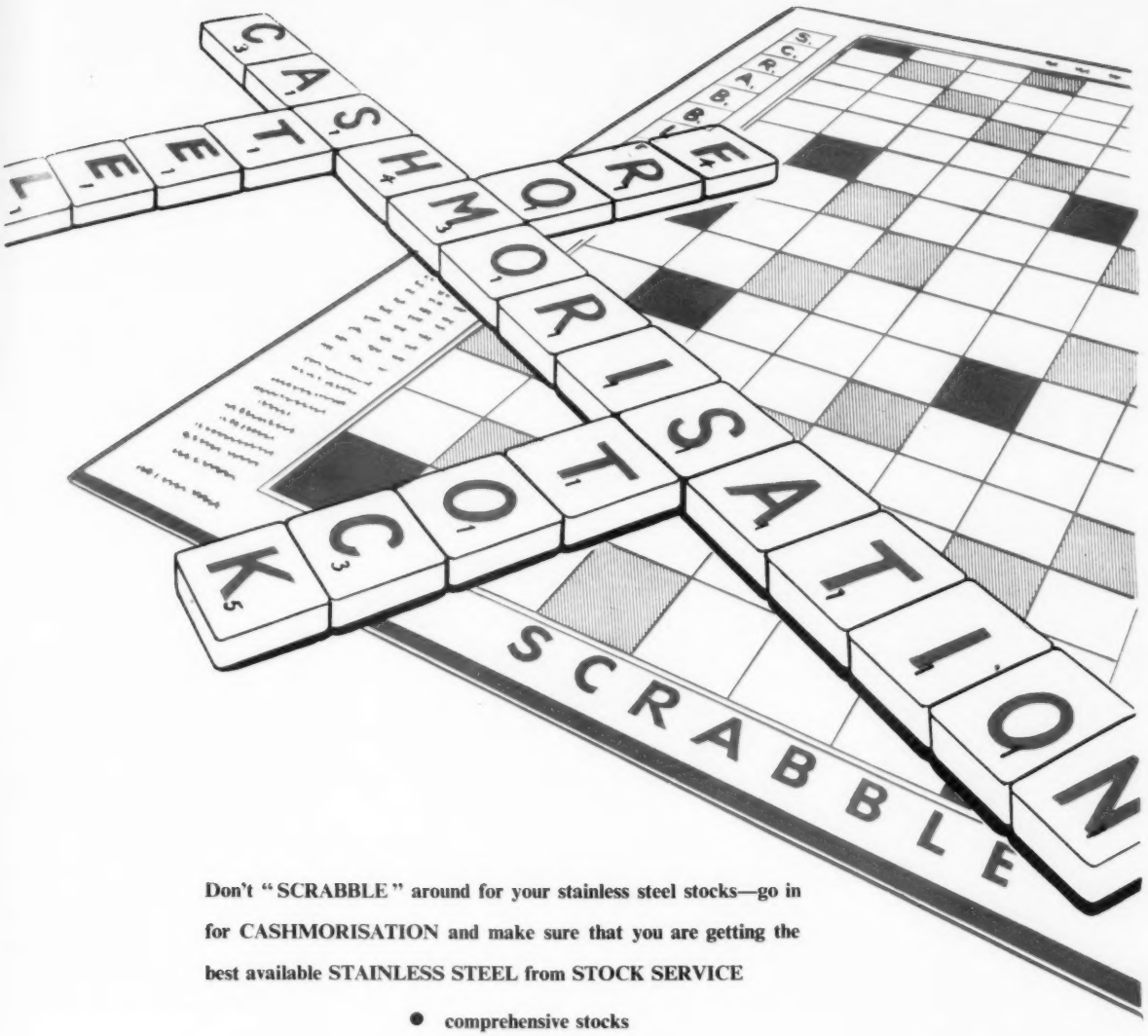
AVERY DIVISION
LOCKHEED PRECISION PRODUCTS LIMITED
SHAW ROAD, SPEKE, LIVERPOOL, 24
Telephone: Hunts Cross 2121 *Telegrams: Lockheed, Liverpool, 24 Telex 62394*
REGD. TRADE MARK: LOCKHEED

These reusable end fittings are made of steel, cadmium plated. Some types also available in gun-metal or light alloy.

Lockheed Avery self-sealing couplings can be used with these hoses and end fittings; they instantly seal off the pipes when disconnected and prevent entry of air when reconnected.

Lockheed Avery

ONE OF THE AUTOMOTIVE PRODUCTS GROUP



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FOR STAINLESS STEEL FROM STOCK

Bars
Flats
Hexagons
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Plate

AID approved

To specifications in general use

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Safe

Conduct

A PLESSIFLEX application on the Bristol Bloodhound

Tough, flexible, seamless, all-metal PLESSIFLEX is the most thoroughly reliable means of conveying fuels and chemicals—whether they are gases or liquids, very hot or very cold, corrosive or inflammable—from one place to another. And this point is overwhelmingly endorsed by engineers in the aeronautical, nuclear, marine and chemical industries.

At pulsing pressures, at high pressures or under vacuum conditions, PLESSIFLEX provides the vital link between those parts in your installations which are subject to continual relative movement.

The basic components of PLESSIFLEX are the result of continuous development and testing, in consequence of which the complete hose units are unrivalled in their high quality. Offered in a range of sizes from $\frac{1}{8}$" to $2\frac{1}{2}$" bore, and in almost any metal you care to name, PLESSIFLEX may be tailored to *your* particular requirements.
Suitably braided for stability, the tube itself is made from material that has been subjected to rigorous pre-process analysis—everything in fact about this versatile, incredibly robust product is shaped to the ends of higher performance and greater safety in fields where such requirements are essential.

Our engineers are waiting to show you how PLESSIFLEX
Regd. Trade Mark

can solve your piping problems

POWER AUXILIARIES LIMITED · Kembrey Street · Swindon · Wilts · Tel: Swindon 6211

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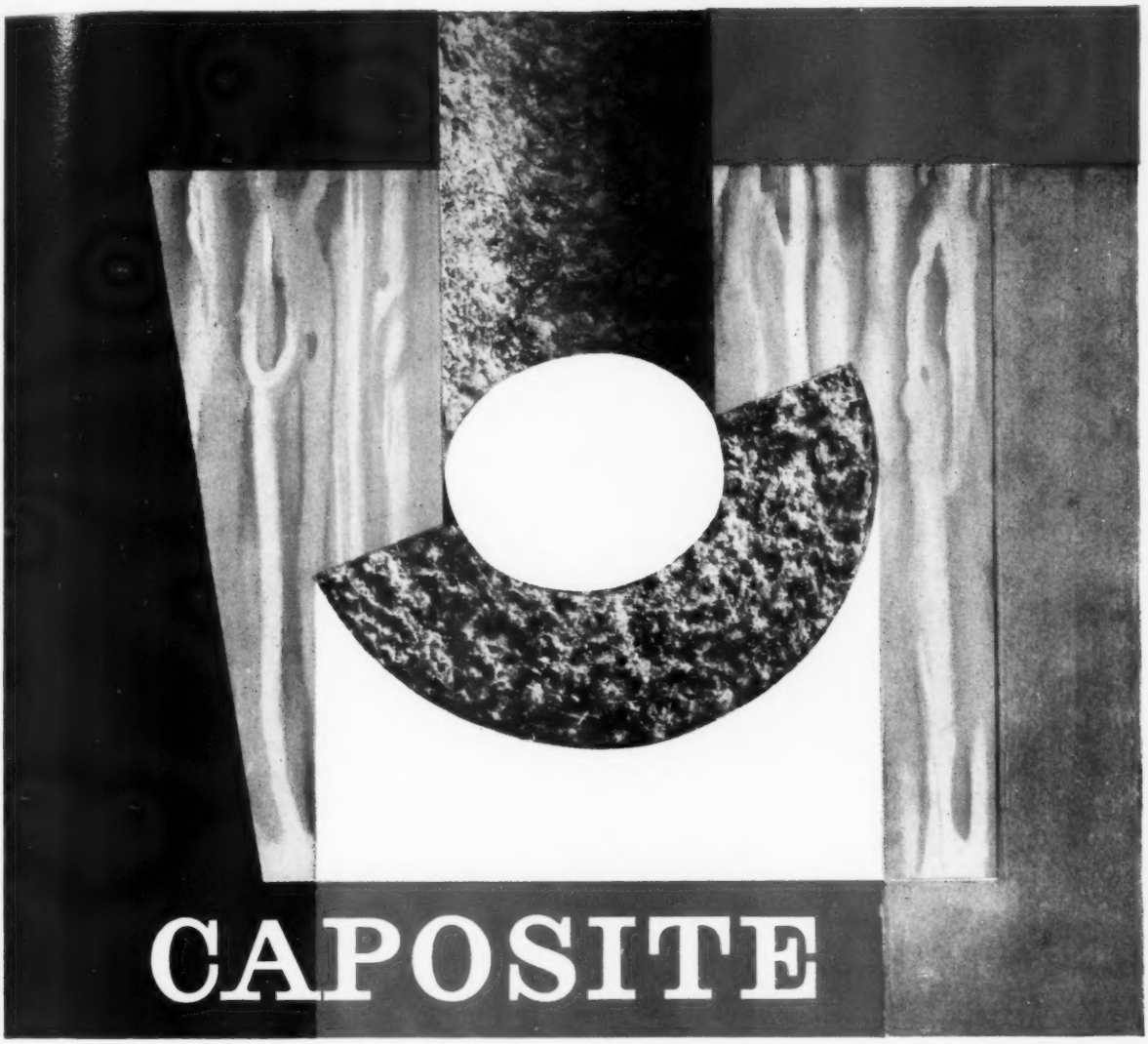
PALI4c

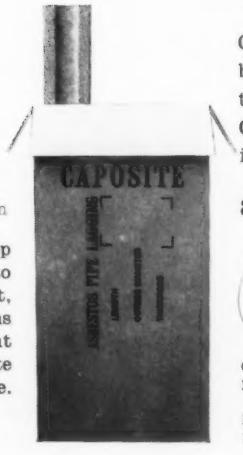


INSULATION

'efficient, economical'

Caposite insulation has high thermal efficiency due to its being made from unique long fibred amosite asbestos from the company's own mines. These long fibres give Caposite great mechanical strength, enable it to be preformed in large sizes, and to be applied as a single layer.

amosite asbestos preformed insulation



CAPOSITE is clean

clean to cut and sweep away—no mess to stick to boots. It comes in light, non returnable cartons which make handy off-cut bins—there's no waste with Caposite.

THE CAPE ASBESTOS COMPANY LTD

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TA1631

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MEETING: NEW CHEM. PLANT — Wednesday

Higher Circuit Pressures
Large Pressure Vessels
must get down to this problem (See Tom)

4 Rods — DEE
12th – 13th – 14th
Thurs.

Spherical or Cylindrical

can they be works built or must they be fabricated on site?

Query: fabric" + inspection of plates thicker than 3" to 4" (especially on site) (Size?)

Query: metallurgical quality of thick plate (What about Ductility?)

Cylindrical vessel is better shape for job
↳ also much easier/cheaper to build

Longitudinal stresses O.K
BUT — Hoop Stress
∴ Barrel Sect" wd. need thicker plate

OR REINFORCED!
How?

BAND-reinforced layer vessel

Alternative is big spherical vessel

NB EXPENSE + SPACE

Paper: Inst. mech. 5/12/58
"Experimental Investigation into the Stress Distribution in a Band-reinforced Pressure Vessel"

multilayer thin reinforcing bands take ½ hoop load
Relatively thin shell ends
Ductility

What it comes down to is this:

instead of big expensive sphere — we have small sphere — plus an inexpensive wrapped (banded) Cylinder

Providing same volume and withstanding same pressure

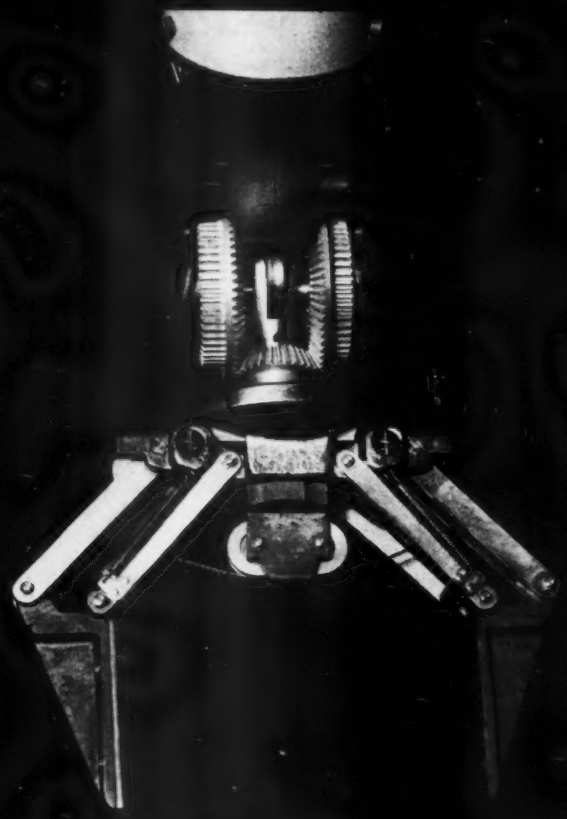
Get on to John Thompson, Wolverhampton who have developed this + inland of fabrication in works and on site

TEL: BILSTON 41121

JOHN THOMPSON GROUP

JOHN THOMPSON (WOLVERHAMPTON) LTD WOLVERHAMPTON

WVP7



Manipulators

The manipulators used at atomic establishments have to operate under exacting conditions. They are constructed of stainless steel and Kanigen plated aluminium and the plate serves two functions. It resists corrosion and, because of the smoothness of the finish, it also assists in decontamination of the component parts from radio-active material; and the combination of stainless steel and Kanigen plated aluminium reduces the electro potential difference between the component parts. These manipulators, manufactured by Savage & Parsons Ltd., are supplied to users all over the world. Kanigen is used on the aluminium parts of the Tong End assembly and the Master Hand assembly.

Kanigen

A HARD & CORROSION RESISTANT PLATE

KANIGEN is a nickel-phosphorus plate deposited by chemical reduction: thickness can be controlled to fine limits and is of complete and uniform coverage.

PROPERTIES:

Composition	92% Nickel 8% Phosphorus
Melting point	890°C.
Electrical resistivity	60 microohm cm.
Hardness	500—1,000 V.P.N. according to heat treatment
Coverage	Extremely uniform

Kanigen can be applied to all ferrous metals, aluminium, copper and brass. The plating plant at Oldbury has now been extended, two extra plating tanks are in operation and enquiries for jobbing plating are welcomed. Full information is available on request.

Albright & Wilson
(MFG) LTD
Kanigen Department
I KNIGHTSBRIDGE GREEN · LONDON SWI

Kanigen is a regd. trademark of Albright & Wilson Ltd

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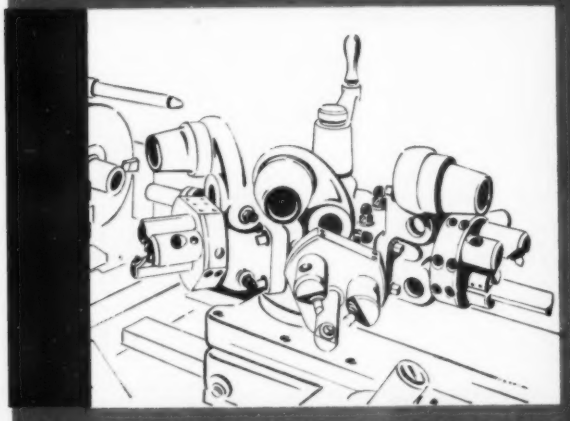
KANIGEN
ALBRIGHT & WILSON

FREE CUTTING BRONZES AND BRASSES



- Free Cutting Brass for use at the highest machine speeds. Available as rods, bars, tubes, solids and hollow shapes.
- High strength Bronzes and Brasses with good machining properties.
- Close metallurgical control at all stages of manufacture.
- Alloys produced to all British and other standard specifications.

THE MANGANESE BRONZE AND BRASS COMPANY LIMITED

HANDFORD WORKS HADLEIGH ROAD IPSWICH
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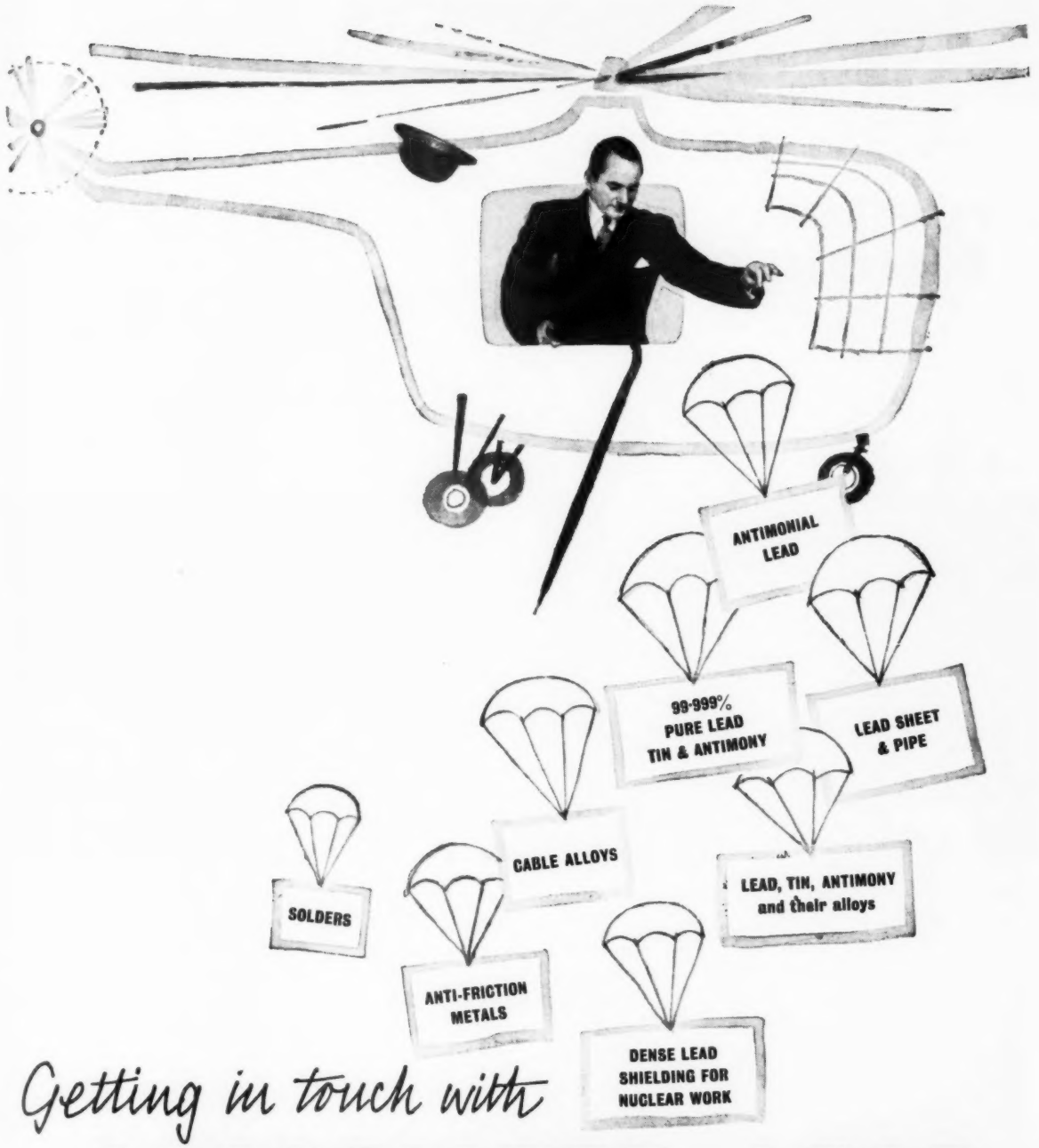

Getting in touch with

ASSOCIATED LEAD

usually leads to better things

No matter how you do it, no matter what your particular industrial need, getting in touch with Associated Lead is bound to lead to better things—better products, better processes—for you and your industry.

Associated Lead Manufacturers Limited is a single company specialising in the manufacture and supply of lead and antimony in all their many forms; alloys; pure metals; chemicals and pigments.

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Export enquiries to: Associated Lead Manufacturers Export Co. Ltd., Clements House, 14 Gresham Street, London E.C.2

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At Bradwell, Essex, N.P.P.C. are building a new nuclear power station for the Central Electricity Generating Board, with a guaranteed output of 300 megawatts. This great enterprise is a commercial venture aiding Britain's economy and emphasising her world lead in the practical application of atomic power for peace.

NPPC

A Greater Britain through Nuclear Power

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GAS WELDING DEVELOPMENT

LECO No.1 All purpose

FLUX COATED Bronze Welding Rod

LE3

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LINCOLN ELECTRIC CO LTD

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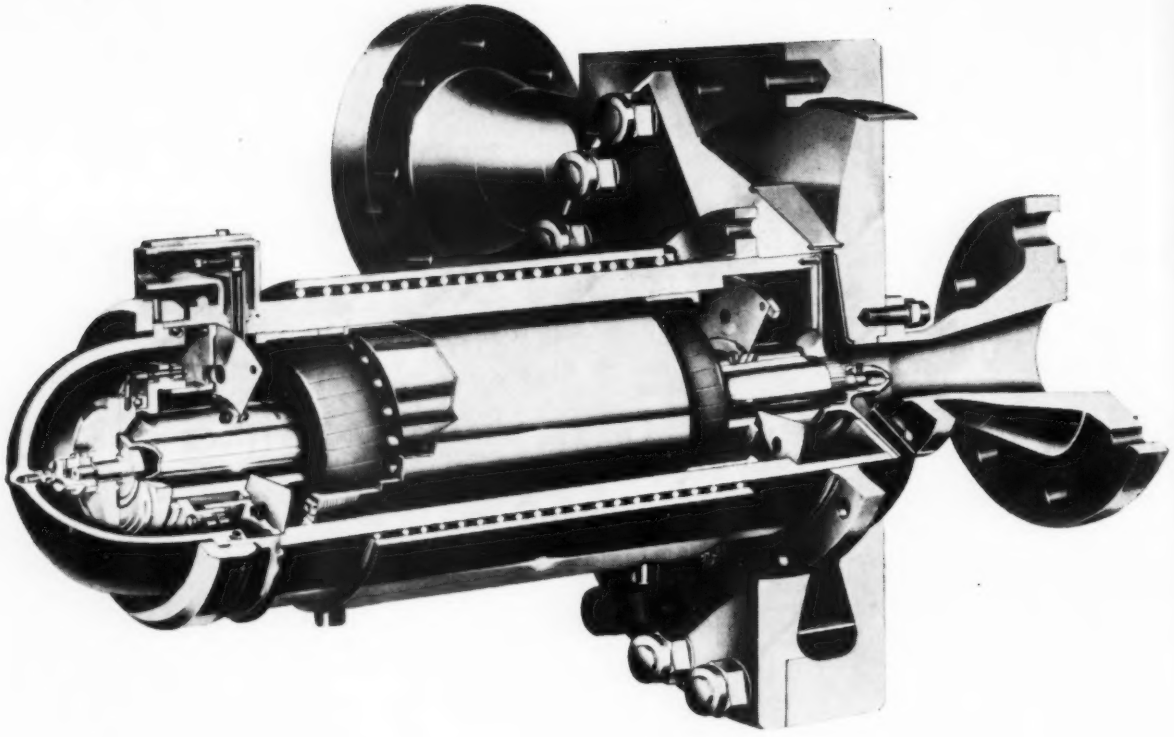

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HAVE DESIGNED A RANGE OF GAS BEARING COMPRESSORS CAPABLE OF HANDLING GASES UP TO...

2,000 psi and 700°C

with input powers up to 2,000 hp
They have many advantages
They are:

Free from lubricant contamination

Totally enclosed, needing no mechanical seals

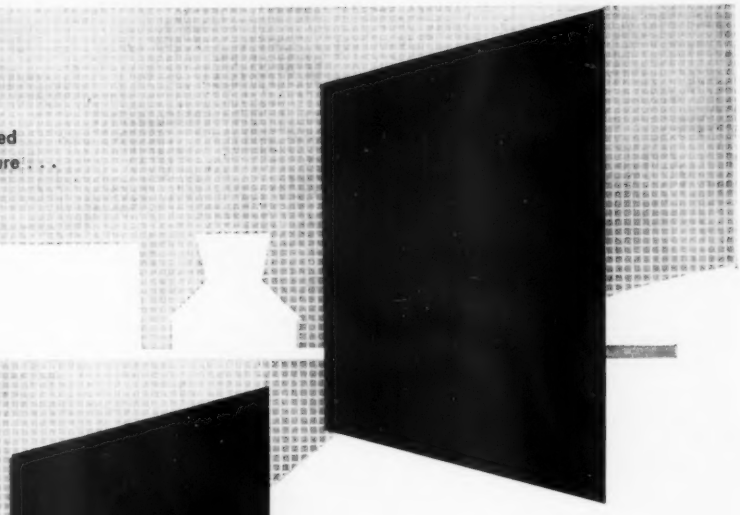
Practically maintenance-free

Capable of operating over a wide range of temperatures and pressures

BRISTOL SIDDELEY ENGINES LIMITED · COVENTRY · ENGLAND

150 MW_e

Nuclear power station
with boiling water reactor.
Development and design aimed
at increasing steam temperature . . .



15 MW_e

Nuclear power station
with boiling water reactor
System General Electric.
Total planning, construction
and initial operation of plant . . .

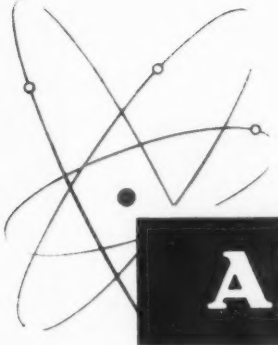
10 MW_{th}

D_2O – tank-type
research reactor.
Supervision of reactor
manufacture,
total planning
and installation . . .

5 MW_{th}

"Swimming pool"
research reactor.
Total planning
and installation.

. . . THESE ARE THE DEVELOPMENT STAGES FOR POWERFUL

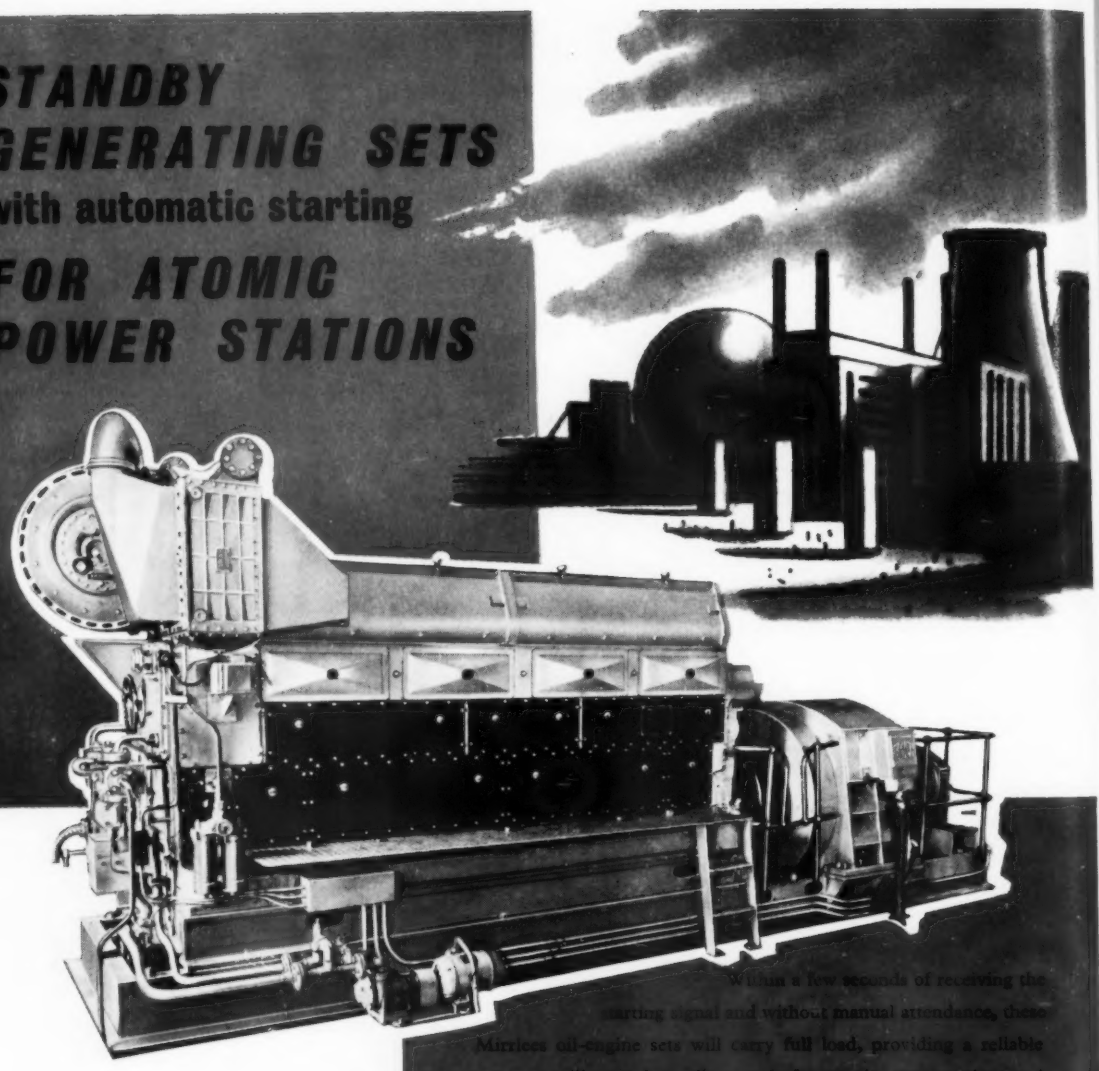


AEG

NUCLEAR SYSTEMS

ZWA 9385 e

STANDBY GENERATING SETS
with automatic starting
FOR ATOMIC POWER STATIONS



Within a few seconds of receiving the starting signal and without manual attendance, these Mirrlees oil-engine sets will carry full load, providing a reliable auxiliary and standby supply for atomic power stations and other installations where it is essential to forestall breakdowns and serious loss due to cessation of mains power supply.

The Mirrlees J and JV Types of engine cover a comprehensive series including 3, 4, 5, 6 and 8-cylinder in-line engines and 12 and 16-cylinder vee-form engines. All can be offered in naturally aspirated or turbocharged form, the latter with or without air aftercoolers. The power range extends from the 210 BHP J3 three-cylinder naturally aspirated up to the 2272 BHP JVS16 sixteen-cylinder turbocharged engine with air aftercooler.

Mirrlees

diesels

MIRRLEES, BICKERTON AND DAY LIMITED

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Nuclear Power
DECEMBER 1959 VOLUME 4 NUMBER 44

VIEWPOINTS *letters to the Editor*

Badges or dosemeters ?

SIR: I would like to make a few comments on the very interesting article entitled 'How a film badge service operates' by J. Dealler in your issue of September 1959. This gives a very complete description of the operation of the service and points out the various advantages of film badge monitoring, particularly where mixed radiation and radioactive chemicals are in use.

By far the most important need for monitoring at present, however, concerns users of gamma-ray emitting substances or high power X-rays for industrial radiography, and the fact that industry in general makes far more use of the pocket electrometer dosemeter suggests that it must have special advantages over the film badge. The most important of these advantages is that the dose can be read at any moment by the operator. The confidence and sense of security given to the operator by such a means of ascertaining the safety or otherwise of his surroundings, cannot be over-emphasized.

The author mentions that the range of these instruments is limited and that they cannot distinguish between 1r and 10r, but of course such figures would *never* be approached in practice since a continuous watch would be kept by the operator on his electrometer dosemeter.

It is rather curious to read that the author considers that a fortnight between readings of film badges is a reasonable period. Users of pocket dosemeters probably refer to them every few minutes when exposed to radiation, and certainly once a day even when not exposed.

It is a pity that the draft regulations of the Ministry of Labour are quoted as a guide to the use of electrometer dosemeters, since it must be remembered that these are, in fact, only a draft and another draft is in course of preparation. The ICRP Regulations, on the other hand, make no distinction between the use of electrometer dosemeters or film badges, merely saying that 'the dose should be measured on any suitable instrument.' This, I feel, is the right way to deal with these matters, by recognizing that there is no one best method but that the most appropriate method to the work in hand be employed. After all, there is no reason to believe that something much better even than the pocket electrometer dosemeter may not be evolved in future, and to tie down regulations to one type only of dose-measuring device would surely be unwise.

Assistant Director, Research J. S. BLAIR
Stewarts and Lloyds Ltd.,
Corby, Northants

• *The Editor welcomes correspondence for publication.*

Vacuum switch

SIR: Referring to our vacuum switch article in the November issue I note that the time scale (1 microsec/cm) and current scale ($1{\cdot}4 \times 10^6$ amperes/cm) on Figure 3 have disappeared during reproduction. Also, the oscillogram is upside down.

Group Leader, G. M. BRACEWELL
High Temperature Physics Group,
Hawker Siddeley Nuclear
Power Co. Ltd.,
Langley, Bucks

▶ *In spite of all the care that is taken, mistakes still seem to creep into the magazine and we apologize to Mr. Bracewell and his colleagues for the unfortunate error in their article.*
Editor

Halogen-quenched tubes

SIR: In his article in your October 1959 issue (*Electronics for radiation detection—Discriminators and allied circuits*) Mr. F. H. Wells describes a GM quench unit and quite rightly states that improved operation is obtained. He does not, however, make it clear that this only applies to organically-quenched geiger müller tubes, and not to the halogen-quenched tubes which are now being more widely used.

Florida and Davey have shown (*Atomics* 1954, **5** p. 229) that in general halogen-quenched tubes may be used in this circuit, but that it is not suitable for high current types. Our work shows that a simple modification of the anode resistance and coupling capacity makes the circuit suitable for all halogen-quenched types. This consists of dividing the resistance equally and taking the pulse from the mid point. The coupling capacity should be reduced from 1000 pico farads to 300 pico farads and all stray capacitance kept to a minimum.

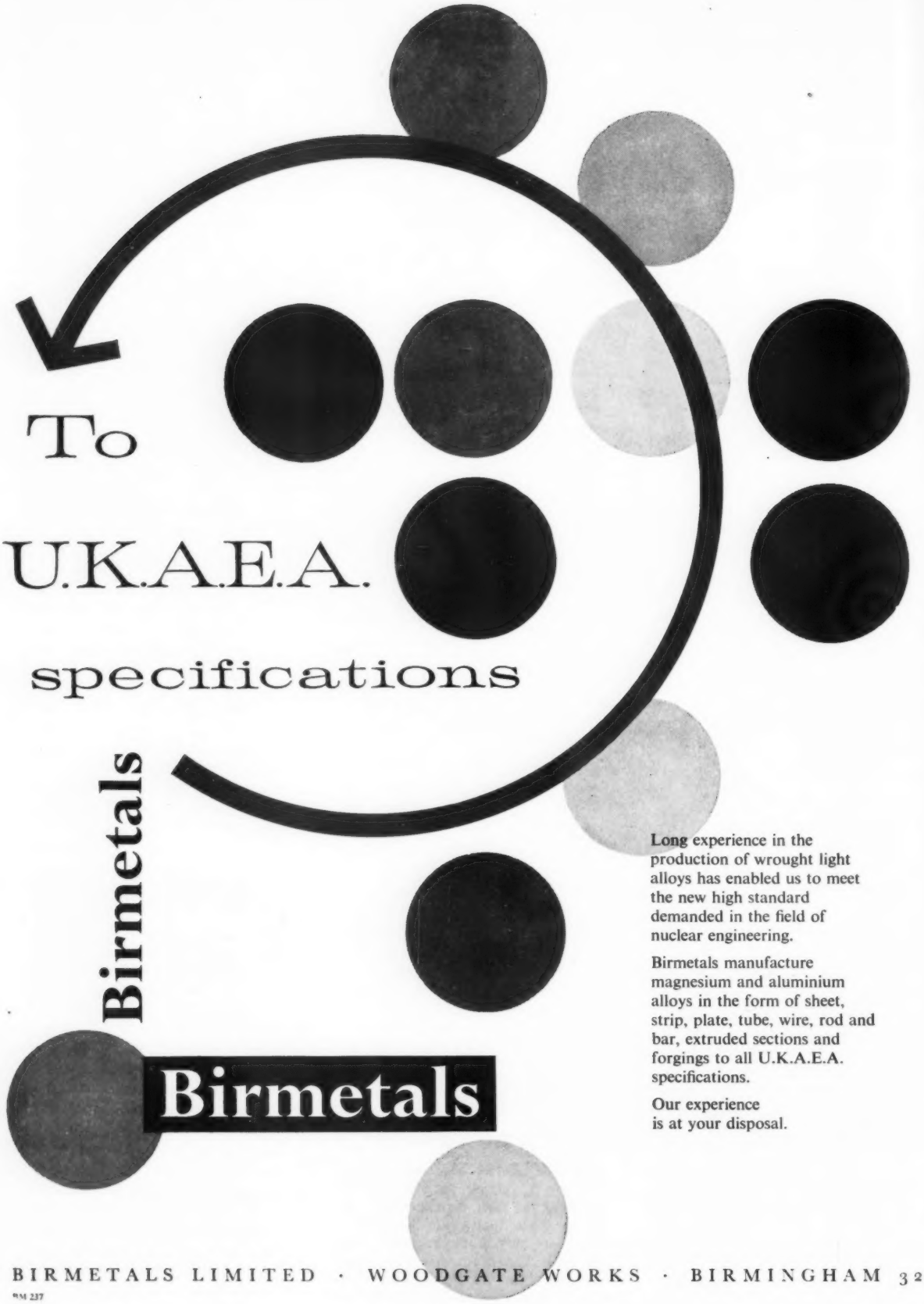
A quench probe is, of course, not required to improve the operation of halogen-quenched tubes, but in providing a known dead time its continued use is probably justified.

X-ray Division, M. J. BUTLER and
Mullard Ltd., IAN W. MACINTOSH
Mitcham, Surrey

PUBLISHER'S COLUMN

A new beginning

Organizing magazine makeup so that the busy man can quickly find the items he wants to read first has always been one of the main aims of Rowse Muir Publications. While readers seem pretty happy on the whole with the present arrangement of NUCLEAR POWER we have heard noises to the effect that it is difficult to find where the magazine actually begins. They open the cover and find the contents on the first page: so far so good. But actual features began, until the last issue, with a half page of publishers column, a half page of letters, another half page of letters, then the leader; and some readers found that on flipping through they could miss some of these altogether. To do away with these half pages meant, of course, abolishing 'next lit' advertisements and reducing the number of 'facers' allowed. Nevertheless this has now been done in order to tidy up the beginning. The contents proper will start with this page, carrying letters and this column, and go straight on through the leader to Worldview. We hope it's now going to be easy for everyone to find what they want.



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OPINION

Dounreay

NOVEMBER 14th MARKED BOTH the end of a very embarrassing period for the Atomic Energy Authority and the beginning of the second stage in the history of atomic power in Britain. The Authority has succeeded at least in starting up its fast reactor; now we can settle down to wait and see what it can do.

When building started in March 1955 the project seemed imaginative and praiseworthy. Then came the snags. A serious fault was spotted in the catchpot design, which had to be changed. Fuel elements already made were reappraised and scrapped; more redesigning followed. As the holdups multiplied and the delays stretched into months the ranks of its critics swelled; references to the DFR became cooler even in the highest levels of the Authority. The appetite for advanced experiments was reduced still further by the Windscale accident, which also robbed the project of many of its staff in the subsequent reorganization.

Vital but suspect

Commissioning finally began a year ago and while the staff toiled to overcome the difficulties described by Mr. Phillips in this issue, the DFR appeared to be languishing in a backwater, absorbing only 10 per cent of the Industrial Group's research effort and well down on the list of priorities. Though it remained officially the key to future plans this was only because no satisfactory alternative had been found. But meanwhile it became increasingly evident that the economics of thermal stations working in isolation are just not good enough and the report of the Select Committee on Estimates last June reminded the Authority that the concept of an integrated system of plutonium-producing thermal and plutonium-burning fast reactors still offers the best prospects for economic power generation. The promise of fast reactors producing electricity at 0·3–0·4d. a unit was even used to justify the first round CEGB stations with their 0·7d. a unit generating costs. The report took the view that the future course of the power programme would be directly affected by the availability or otherwise of fast reactors in the early 1970's, and said that the problems must be solved by 1966 at the latest.

Why are fast reactors so desirable? It may be worth recalling the remarks of J. W. Kendall and T. M. Fry in their paper to the first Geneva conference: 'The fundamental reason for developing the fast reactor was that it seems capable of more efficient utilization of uranium fuel than a system based on thermal fission. The energy content of the 238 isotope is little different from that of 235 but when natural uranium is fed into a thermal system all but a few per cent, depleted in its content of 235, must be thrown onto the ash heap. The need to conserve uranium may not be great at present but ultimately the possibility, afforded by the fast system, of using almost all of the uranium should be most attractive.'

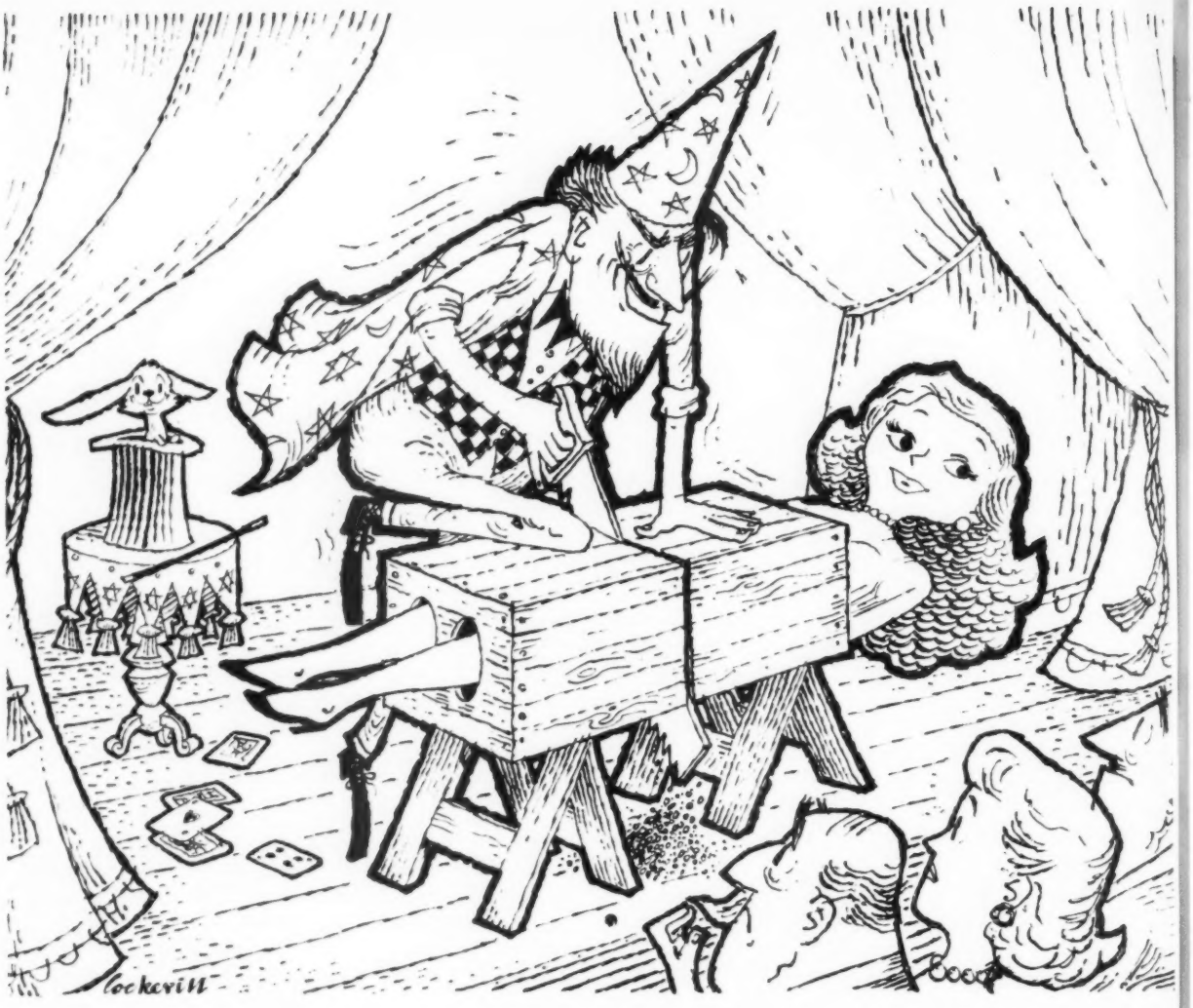
Prospects still bright

This is just as true today as it was four years ago. By burning the plutonium produced from thermal reactors the fast reactor could increase the useful energy value of one ton of uranium from ten thousand to a hundred thousand tons of coal. By the successful application of the breeding principle the utilization might be increased ten times more.

The technological problems to be overcome are formidable. The DFR produces seventy-two megawatts of heat in a core of a few cubic feet. Liquid metal has to be used to remove it and experience in this field is neither ample nor reassuring. A satisfactory design of fuel element to keep its shape and strength after the burnup of a large proportion of its constituent atoms must be achieved. Control problems are more complex than with thermal reactors and the results of a runaway potentially much more serious.

Next one must be simpler

As a first attempt to cope with these it is not surprising that the reactor at Dounreay is complicated, cumbersome and heavily overdesigned. Its use may enable simpler solutions to be found. The fact that it will produce, when fully operational, about fifteen megawatts of electricity to feed into the domestic system is merely incidental. The main task is to gain the experience necessary to confirm and design the next step—a prototype fast reactor for the commercial generation of electric power.



'HALF-LIFE'

But there's no "magic" about radioactivity. Both its intensity and its rate of decay can be measured. The standard of comparison between different materials is taken as the period during which levels of radioactivity are progressively halved—the "half-life".

Titanium, for instance, has a very short half-life—after exposure to radiation, it is quickly safe to handle again.

It is therefore ideal for components of the charge/discharge equipment of a nuclear reactor.

It was I.C.I. Metals Division which, three years ago, gave Britain its first wrought titanium. As new markets have developed, the Division's facilities for producing the metal have greatly expanded. And the unique technical knowledge acquired in taming titanium has been put to good use in developing other "new" metals, with a life (and a half-life) of their own.

ICI METALS DIVISION

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Worldview

the month in atomic energy

New power group

Babcock & Wilcox are to collaborate with Humphreys & Glasgow in the designing, fabrication and selling of small power reactors in the 20-30 MW range. Following the termination of the agreement between Alco Products Inc. of New York and Humphreys & Glasgow Ltd. in connexion with nuclear power units up to 30 MW capacity, the British company will concentrate on a similar range of power stations but will utilize PWRs designed and built by Babcock & Wilcox Ltd. This arrangement will enable a purely British group to enter the field of small stations for undeveloped countries in line with the IAEA's programme for the coming year.

Site for ICSE fixed

The Atomic Energy Authority have finally decided on a site for their new thermonuclear research establishment. The AEA are now seeking the necessary approvals to acquire and develop a site of some 175 acres within the perimeter of the Royal Naval Airfield at Culham in Oxfordshire. One of the immediate tasks at this site, when approved, will be the construction of ICSE, intermediate current stability experiment (see *Worldview*, August). This location has been chosen because of its proximity to AERE, the National Institute for Nuclear Research, Harwell, and Oxford University.

INTERNATIONAL

Power for the future

At the recent two-day conference of the Round Table for European Problems the need for a coordinated energy policy for the whole of Europe was stressed. The present coal situation has brought about conditions which necessitate the reappraisal of nuclear power programmes as well as drastic reorganization within the coal industry itself. The need for atomic power has ceased to exist, stated Mr. Austin Robinson, President of the Consultative Committee on Energy for OEEC; he said there would be no shortage of conventional fuels over the next fifteen years. There was, however, still a long-term need for nuclear power, as between the years 2000 and 2025, Europe's power consumption would be four to seven times greater than at present.

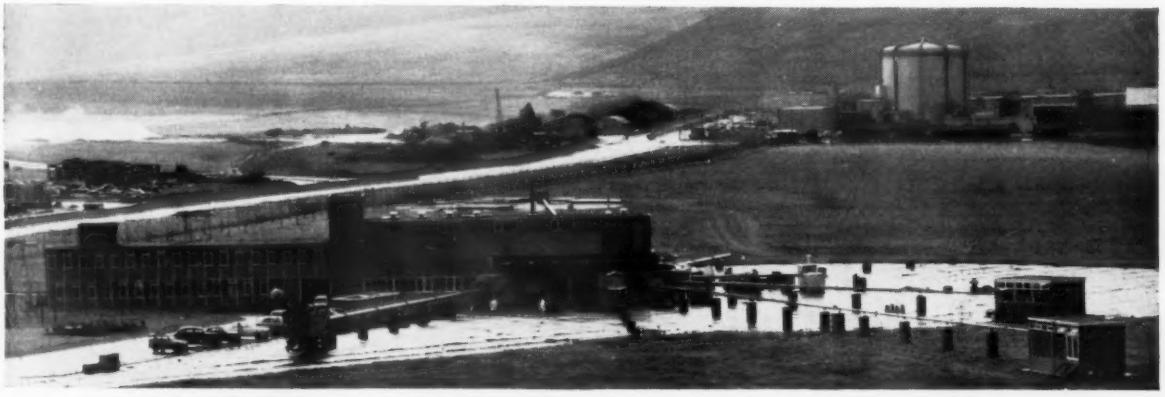
It was proposed that nuclear developments and construction should be internationally integrated and form part of a complete power scheme for Western Europe. The European Nuclear Energy Agency of OEEC stated that to take advantage of the respite granted, joint action in coordinating research programmes which were too big for individual countries should be initiated to investigate new types of reactors.

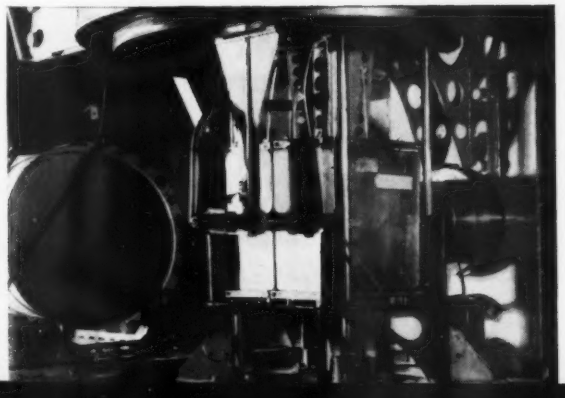
Slow but sure

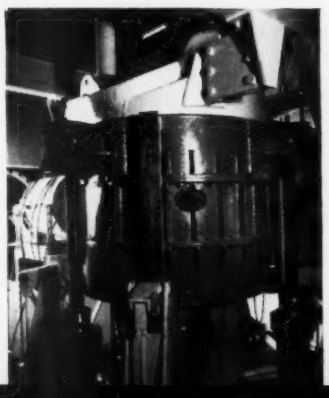
Brussels—Although detailed proposals have not yet been submitted in full under the Euratom-US Agreement, five enterprises have announced their intention to submit detailed projects. The only established project so far is the Italian Elettronucleare-SENN BWR to be constructed by the International General Electric Company.

The German AKS project for an OMR is well forward and will be constructed by Atomics International in conjunction with its German associates, Interatom. Brown Boveri Company of Mannheim will be responsible for the civil engineering aspects and all that remains to be settled are the final details of administration and finance.

The third project has been submitted jointly by Electricité de France and a Belgian Group, Centre et Sud. While the site survey at Chooz on the Meuse near







HARWELL A programme of neutron time of flight experiments is now being undertaken by a combined AEA and Commonwealth team. The facility (above) consists of an electron linear accelerator in conjunction with a multiplying target assembly (see this month's Industrial Newsdesk). The neutron booster is seen with its lead shield open and closed (left and right)

NEW POWER CHIEF The Hon. Richard Wood has been appointed Minister of Power in the new Government. Previously he was Parliamentary Secretary to the Ministry of Labour and National Service which he joined in April 1958, after having been Joint Parliamentary Secretary to the Ministry of Pensions and National Insurance since December, 1955

the Franco-Belgian frontier has been completed, definite reactor proposals are still to be worked out. Similarly, the Dutch project has not yet been finalized, but a detailed study is being carried out by the SEP, an association of all the Dutch electricity producers.

Scheduled for completion in the second stage of the Euratom-US programme is the West Berlin project for a 150 MW station to be in operation by 1965. Detailed technical planning is already under way and discussions have taken place between members of the Land of Berlin and Euratom in connexion with the special health protection requirements due to the unique siting problems involved. The plant, when built, will be operated by the West Berlin utility com-BEWAG.

During a recent visit to America, the President of Euratom, Etienne Hirsch, stressed that while the proposed programme was not being brought into effect as quickly as originally planned, conditions were still favourable, and he stressed that it was to be a joint venture, meaning that both American and European industries would take part. He went on to emphasize that neither the US Government nor Euratom should go into the power reactor business or become directly involved in the management decisions to proceed with this or that reactor. The joint US-Euratom programme has been designed solely to bridge part of the gap between the costs of conventional and nuclear plants.

CANADA

New centre planned

Chalk River—Atomic Energy of Canada Ltd. is to build a nuclear energy research and development centre in Manitoba. The directors of the company have recommended to the Federal Government that to permit Chalk River establishment to operate at its maximum efficiency it should not continue to expand. Preliminary discussions have been held with the Government of Manitoba and it is expected that site surveys will be carried out shortly and the site selected by early next year.

The construction of the buildings and laboratories and the installation of equipment and technical services at the site will begin with the next major project to be undertaken by Atomic Energy of Canada Limited in the research and development field. This will probably be an organic-cooled, heavy-water-moderated power reactor experiment.

ITALY

US help for power plant

Milan—A credit of $M34 to assist the establishment of the Enrico Fermi plant by SELNI has been given by the Export-Import Bank of Washington. Initially the output of this station will be 165 MWe but it will be eventually stepped up to 225 MWe. Westinghouse Electric is providing the nuclear equipment which will be a heterogeneous pressurized reactor using light water as both moderator and coolant and having a three-region, three-cycle core. A heat output of 615 MW has been guaranteed and future fuel loadings are expected to raise this output to 843 MW. The reactor fuel will be slightly enriched uranium in the form of uranium dioxide clad in stainless steel. The core will contain 39,000 kg. with an enrichment of from 2·6 per cent to 2·8 per cent and will permit replacement in one-third of the core loading.

This plant will be the largest unit in Europe to be built for a private company containing American nuclear equipment, and is expected to achieve criticality within the next four years.

THE DUKE VERSUS MERLIN H.R.H. The Duke of Edinburgh runs into a little trouble when trying to start the Merlin research reactor at the recent official opening. It refused to function at first, but the Prince returned to the attack later after the staff had worked on it, and succeeded in starting it up

LARGEST REACTOR IN GERMANY The final stages of construction are now being completed on this 12 MW research reactor at Karlsruhe. When in operation the centre, costing some £M17, will employ 1500 scientists and research workers on joint programmes for Euratom and the Technical University of Karlsruhe

SPAIN

Site work for No. 1 starts

Madrid—At Santa Maria de Garona, in the Ebro valley, work has started on site preparation for the first Spanish nuclear

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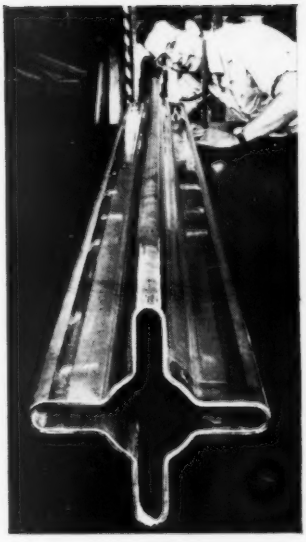
Dresden ahead of Schedule

On October 15 (see last month's Worldview) the 180 MW BWR designed and built by General Electric for the Commonwealth Edison Co. went critical, some six months ahead of schedule. Pictures show : **1.** During preliminary trial running of the turbogenerators, the opportunity was taken to give a final check to the instruments and controls. **2.** To the right of the spherical reactor containment vessel is the exhaust chimney for blowing generated steam to atmosphere from a condenser in the event of an emergency. **3.** During fabrication of reactor components the guide tubes for the control rod drives, made by GE's Atomic Power Equipment Department, were checked by special depth gauges. **4.** Continuity of cross-section through the length of the zircaloy fuel channels was ensured by special gauges. When completely loaded, the Dresden core will hold 488 elements, each containing 36 zirconium alloy-clad fuel rods, 9 ft. 9 in. long and slightly more than half an inch in diameter. **5.** Working to a tight construction programme, the bottom core support plate was passed by the inspecting authority for installation into the reactor vessel during April 1959. When the reactor is brought up to full power during the first half of 1960, the reactor will be producing 626 MW gross heat. The coolant flow will be 25·6 × 10^6 lb/h at an output pressure of 1020 lb/in^2 and temperature of 542·5°F. Operating at full power the net efficiency of the plant will be 28·8%



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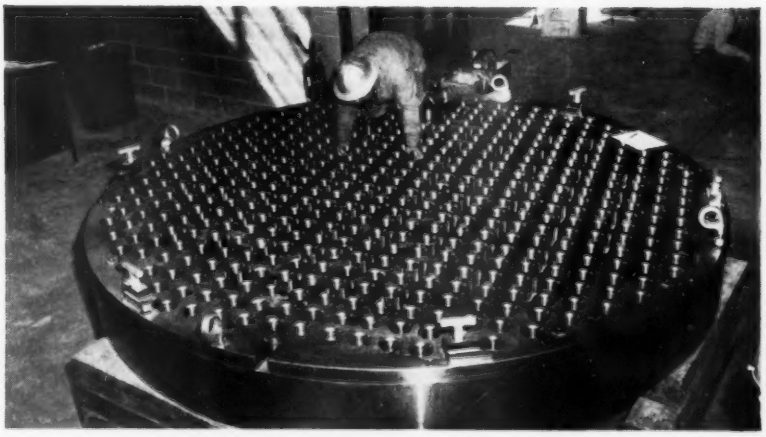


power station. The type of reactor to be installed will not be finalized until 1961 but it is estimated that the plant will eventually have an output of 250 MW, using two turbogenerators of 125 MW each. When completed, the project is expected to cost some M9750 pesetas.

SWEDEN

Power plans cut

Stockholm—The Swedish State Power Board have decided that the R4/Eva power plant project, originally scheduled to be completed by 1965, is to be postponed. At the same time British and American groups have been informed by the Board that nuclear power generation is not considered as being economic in the forseeable future and the earlier enquiries for plant will not be proceeded with.

In collaboration with the Swedish Atomic Energy Company and local manufacturing companies it is proposed, however, to continue work on the use of a natural-uranium-fuelled, heavy-water-moderated reactor of Swedish design, with a view to having a full-scale power plant in operation by the end of the 1960's. Work will continue on the R3/Adam project for space heating.

In place of the Government's plants, AKK, a nuclear power development consortium formed by leading Swedish private and municipal power producers, are proposing to build a small plant by 1965. It is envisaged that an American 50 MW BWR, designed by either General Electric or Westinghouse, could be built under licence in Sweden at a cost of between £M8½ and £M10½. Firm tenders from the Swedish representatives of the American companies have already been invited.

UNITED STATES

New reactor design

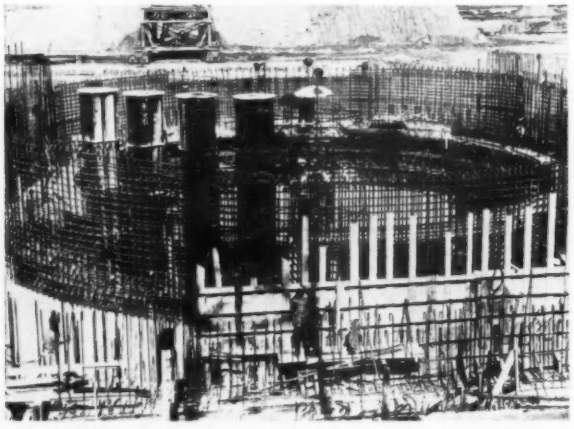
Baltimore—The Nuclear Division of The Martin Company have been awarded an AEC contract, valued at nearly $M1, for the development and first critical experiments of a liquid fluidized bed reactor, LFBR. This reactor will be in the form of a large upright cylinder and the fuel will consist simply of a heap of pea-sized pellets of slightly enriched uranium completely immersed in water inside the cylinder.

While water is at present being used as the 'fluidizing' liquid in the reactor core, organic materials are also being studied. Under this contract, Martin-Nuclear will study abrasion effects on various types of fuel pellets, both with and without metal cladding, as well as conducting zero power tests. Already the effects of abrasion has been greatly reduced by the addition of powdered graphite to the water in the reactor and is anticipated by Martins that the graphite will also improve the heat transfer characteristics.

VIET-NAM

Research in the Far East

Delat—A grant of $350,000 towards the cost of establishing a nuclear centre in Viet-Nam has been made by the US Atomic Energy Commission. Under the director of Prof. N. F. Buu-Hoi, Director General of the Office of Atomic Energy of Viet-Nam, a local company will carry out the construction, supervised by Kaiser Engineers Inc. The reactor will be a multi-purpose, 100 kW Triga Mark II, manufactured by General Atomics of the General Dynamic Corporation.



LATINA While progress has not been made as quickly as anticipated, the biological shield reinforcement with cemetry tubes is approaching ground level and the major portion of the reactor pressure vessel bottom dome and first ring assembly have been completed

WORLDBRIEFS

• **International** Under the 1955 agreement of cooperation between the US and the UK, it was announced on November 16 that technical information on the development, design and operation of advanced gas-cooled reactors is to be exchanged between the two countries. This will apply only to the existing AGR's at Oak Ridge and Windscale, with the latter's associated facility, Hero. The information exchanged will be made available to industry.

• **United Kingdom** Although all the boilers have been erected at Bradwell, the overall project is now running six months behind schedule.

• **Finland** Approaches have been made to the United States for the supply of enriched uranium for fuelling a small research reactor to be built near Helsinki.

• **New Zealand** A three-million-volt particle accelerator, costing some £80,000, has been ordered from the US for the Institute of Nuclear Sciences at Gracefield. This will be the institute's first major piece of equipment.

• **Russia** A delegation of scientists, headed by Prof. Vasily Emelyanov, head of the USSR Council of Ministers' Central Atomic Energy Administration, have visited American atomic installations.

• **Switzerland** At the request of the government, an advisory panel from the IAEA is to carry out a technical evaluation of the safety aspects of Diorit, a 12½ MW research and materials testing reactor.

• **United Kingdom** The Radioactive Substances Bill has been published. This will, with the exception of the AEA and other Government establishments, control the use of active materials and the disposal of waste radioactive materials. Penalties for non-compliance include fines up to £100 and imprisonment.

• **United Kingdom** **Prof.** C. T. R. Wilson died on November 15 at the age of 90. He introduced the cloud chamber technique in 1911 and was awarded the Nobel Prize for Physics with the American scientist, Prof. A. H. Compton, in 1927.

• **United States** The AEC's Argonne Fast Source Reactor, AFSR, is now critical.

• **United States** A General Atomic's Triga Mark II is to be installed at the Kansas State University and is scheduled to be in operation in late 1960.

• **United States** Two PWRs of the land based prototype plant for large surface vessels have operated in parallel at full power. Known as the A1W, this is the first US unit to have two reactors powering one propeller shaft.

• **United States** The AEC has revised its specification for small pressurized water reactors for power generation to include a conventionally-fuelled superheater.

• **Yugoslavia** An investigation at the Boris Kidric Institute is to be held, in collaboration with the IAEA, into the accident which occurred there last year.

DOUNREAY FAST REACTOR

November 14:
The breeder goes critical

FOUR YEARS and eight months after construction began, the 15 MWe fast breeder power reactor at Dounreay went into operation at 10.52 a.m., November 14. It was actually started up by Mr. William Munro, a charge-hand process worker. Dr. Hurst, director of the Dounreay Establishment, said later that this was because Munro was on normal duty, 'and we thought it best to let the driver drive'. Others present included Sir William Cook, Mr. J. L. Phillips, and Mr. P. T. Fletcher. Three visitors from America were two from the Enrico Fermi project, Messrs. Shudko and Homeister, and Dr. W. Loewenstein of the AEC.

The reactor will now be cautiously operated at low power for a few months and may then be shut down if any further modifications are found necessary. It will later be worked up to its full power of 15 MWe by stages and connected to the distribution network.

The centre of the plant is a hexagonal core 21 in. high and 20·5 in. across the flats, made up of 45% enriched uranium fuel elements surrounded by a blanket of natural uranium rods. The small size of the core and its high heat rating make it essential to conduct the heat away rapidly. This is achieved by placing the whole of the core and blanket in a stainless steel vessel filled with a liquid metal coolant, sodium-potassium alloy. It is circulated by electro-magnetic pumps through the vessel and through twenty-four heat exchangers arranged radially outside it. The heat exchangers consist of two concentric stainless steel tubes, the inner one carrying the hot radioactive liquid metal which is circulated through the core, and the outer one non-radioactive liquid metal which is piped to a heat exchanger house and used to raise steam. The steam produced in the heat exchanger house can either be used to drive the turboalternator which is installed, or the heat can be rejected to sea water condensers. The complete reactor with its primary heat exchanger circuits is installed in a concrete vault within the 135 ft diameter steel sphere which dominates the site.

The only other fast breeder reactors in the world are the 150 kW EBR1 at the US National Reactor Testing Station in Idaho, and a 5 MWt Russian plant. The DFR is the first power reactor experiment of any size, and will provide the experience necessary for the design of a full-scale prototype fast power station. Other fast power reactors down for completion soon are the American 16·5 MWe EBR2 and the 100 MWe Enrico Fermi plant, both due critical next year.

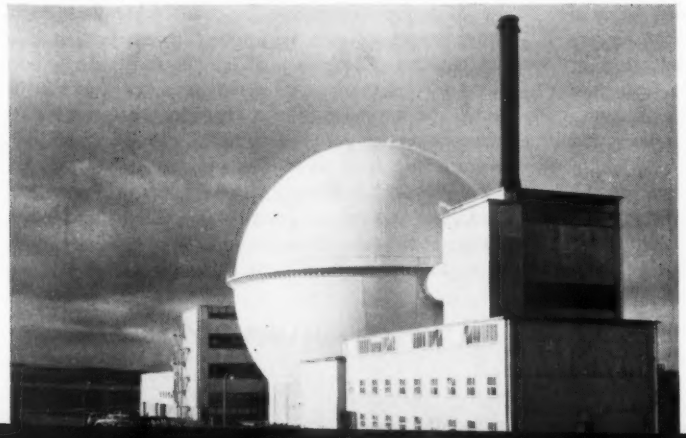
ON THE EDGE OF THE LAND Bounded by the fast reactor complex on the left and the materials testing reactor on the right the Dounreay establishment stretches over half a mile along the shore of Pentland Firth

MAIN REACTOR DATA

Output	72 MWt gross 15 MWe gross
Fuel	Enriched U seed Natural U blanket
Canning	Seed: outside 0·02 in Niobium inside 0·02 in Vanadium Blanket 0·036 in. stainless steel
Core size	20·5 × 21 in
No. of channels	367 seed 1872 blanket
Loading at rated power	800 kg enriched U 66000 kg natural U
Coolant	Sodium/potassium
Max fuel temp	1·510°F
Coolant temp	392°F inlet 662°F outlet
Coolant flow	359 kg/sec in core
Containment	135 ft dia sphere
Control	12 groups each containing 10 fuel elements

● For more information on the Dounreay fast reactor and a coloured wall chart giving a large cut-away drawing see the June 1957 issue.

THE FAMOUS SPHERE has just been cleaned up and painted: compare with illustration on the top left of the page, taken a few months ago. The sphere is flanked by the heat exchanger house (left) and the control room and administration block (right) in front of the active fuel element store



DOUNREAY FAST REACTOR

Commissioning and start-up

by J. L. PHILLIPS, B.Sc., A.R.I.C.
Manager, Fast Reactor Project, U.K.A.E.A.

Bringing the world's most advanced power reactor experiment through final testing and into operation was a slow and difficult process. Here is the story by the man in charge

THE DOUNREAY FAST REACTOR is not a production plant in the generally accepted sense of the term. The end product for which it has been designed is an increased knowledge of the operational characteristics of this type of reactor, which, because of its small core and consequent high heat rating, presents very different problems of operational stability when compared with the very much larger thermal reactors with their large heat capacity.

The reactor is essentially an experiment to provide information on fast reactor behaviour, and to provide a facility for development of a satisfactory fuel element which must combine the necessary strength and rigidity for normal handling and operation with the ability to withstand the burnup of a large proportion of its constituent atoms without significantly altering its shape or strength.

The reactor will produce considerable quantities of heat and the installed equipment includes a primary coolant system to remove up to 72 MWt from the core and blanket, and a secondary coolant system to transfer up to 30 MWt from the primary system either to water or to produce steam. (Space has been left in the heat exchanger building for installation of another 30 MW of secondary heat exchangers when required.) When steam is being produced, it will be used to operate a 15 MW turbogenerator unit which has been installed. A by-product of reactor operation will, therefore, be electrical power, and facilities exist for feeding this power into the distribution network of the North of Scotland Hydro Electric Board.

CONSTRUCTION TESTS

The experience gained from this reactor will be used in the concept and design of the prototype fast reactor which will have as its aim the economic production of power. Although an experiment, it is on such a scale that the reactor and its ancillaries constitute a fair-sized assembly of complicated equipment, and commissioning and start-up presented very many novel problems.

Considerable attention was paid in the design of the primary circuits to the prevention of coolant loss. This is because the residual fission product heat on shut-down after operation at even moderate powers would be sufficient to melt part of the core in the absence of coolant. In addition to taking precautions such as double walling all parts of the primary circuit, and providing leak detectors in the interspaces, the circuit throughout was designed to the highest possible standards. There are 24 primary circuits (see Figure 1), each containing an electromagnetic pump, a main heat exchanger, a smaller heat exchanger which operates continually on the thermal syphon system, a flowmeter, and a by-pass circuit containing an expansion tank, flowmeter, and either a hot trap, cold trap, or one of several types of meter for determining oxide content of the liquid metal coolant. All material in contact with liquid metal is of 18/8/1 stabilized stainless steel and all tubes were drawn and examined by specialized techniques. All shop and site welds were butt welds which were subsequently radiographed and leak tested. Stress relieving was applied to all heavily worked sections, and vessels and pipe work were tested hydraulically before leaving works. The circuits do not contain any valves and they are anchored only at the connexions to the vessel in order to permit free movement under changing conditions of temperature.

After final assembly on site, an overall pressure test of the 24 primary circuits and the reactor vessel was carried out. For this test the primary circuits were as near as possible in the normal operating state which would be with nitrogen at 50 lb/in² pressure above the liquid metal surfaces. Because of late delivery, blanks had to be fitted in place of certain items, e.g. cold traps, sampling devices and corrosion meter.

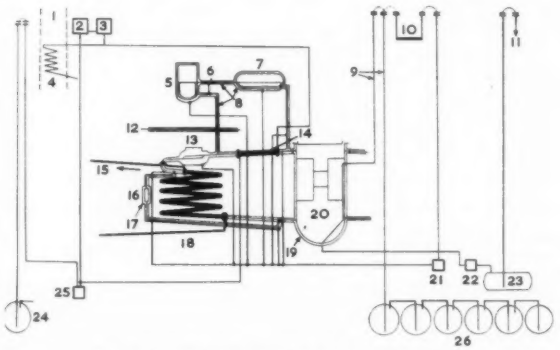
The main problem of pressure testing a circuit of such size and complexity lay in the temperature correction which would have to be applied in interpreting the pressure changes. The effects of temperature changes were reduced by installing a reference pressure vessel inside the circuit and measuring the changes in pressure between this reference vessel and the circuit itself. The installed temperature instrumentation was supplemented by extra thermocouples and resistance thermometers. Manometers were fitted to all volumes adjacent to the reactor and into which leakage could take place.

Similar pressure tests were carried out on the 12 second-

ary circuits, connected in pairs, and upon the thermal syphon system. The leak jackets surrounding primary circuits and the reactor vessel were also tested in the same manner.

As indicated earlier, the problem of the effects of temperature changes was a considerable one. At 55 lb/in² g a change of 1°C would cause a pressure change of 6·66 in. water gauge, whereas a leak rate from the system of 1000 cc/h would only give a change in pressure of 0·082 in. water gauge in 24 hours. Although due regard was paid to the accuracy of the temperature measurement, as the circuits covered a large area the temperature measurements were widely dispersed and there were significant changes of temperature from point to point. Assumptions were made, therefore, by which proportionate volumes were allocated to the measured temperature points and the temperatures weighted in this way.

Despite all these precautions, there was a considerable scatter about the mean line of pressure with time, of the order of ± 4 in. water gauge, of which instrument accuracy and reading errors could account for about ±3·4 in. The effects of temperature variation on the secondary circuits was larger—as expected—than for the primary circuits. The measured leak rate varied from day to night and



The primary heat transfer circuit (Fig. 1)

1. Cooling air drawn over by chimney suction
2. Expansion
3. Cold trap
4. NaK/air heat exchanger (in chimney)
5. Cold trap, hot trap, coolant sampler or corrosion meter
6. Flowmeter
7. Expansion tank
8. Leak jackets
9. Primary circuit charging pipes
10. Ring main
11. Pipe to dump tank
12. 2-in. bore ring main
13. EM pump
14. Thermal syphon heat exchanger
15. Pipe to secondary heat exchanger
16. Coolant monitoring system
17. Leak jacket
18. Primary heat exchanger
19. Leak jacket
20. Reactor vessel
21. Circuit leak detector (24 off)
22. Vessel leak detector
23. Buffer tank
24. Thermal syphon dump tank
25. Solid waste collecting vessel
26. Primary circuit dump tanks

in some cases a negative leak rate was shown and must have been due to an error in the assumption of proportionate allocation of volumes to the temperature measuring points.

Nevertheless, although the results were subject to the errors indicated, they did in fact demonstrate that the overall leak tightness of the plant was good for a circuit of this size and complexity. It was considered that the tests had demonstrated that the liquid metal circuits, in particular the primary circuits, were sound and the final stages of construction were continued.

Construction work had reached the point by the end of November 1958, where, although final completion was impossible because of non-delivery of certain items, it was nevertheless obviously of advantage to the project for Operations Staff to take over the plant and to commence commissioning. Construction was left to be completed by the Site Engineering group as possible and convenient to fit in with the commissioning programme. The reactor sphere and contents were therefore handed over from Construction Branch on December 8, 1958.

Earlier in 1958, Operations Group had already taken over the ancillaries, i.e. sea water pump house, diesel generator house, heat exchanger house, electrical link building, administration building and control room. In each of these buildings and in the sphere, installation was carried out by Construction Branch in accordance with test schedules drawn up by the Design Office. At these tests representatives of the Establishment Engineering and Operations groups were in attendance, and assisted in many cases, in particular with the pressure testing described at some length above. The take-over was therefore a gradual process culminating in the final date of December 8, 1958.

STAFF TRAINING

During 1955, Zeus had been constructed at Harwell in order to provide basic physics information required for certain design aspects of the Dounreay Reactor. The selection of certain personnel for eventual duty at Dounreay was made at that time so that they could work on Zeus and at the same time acquire a more specialized knowledge of the physics of the system.

As construction progressed, more of the staff were recruited and spent periods in the Design Office, and working on reactors at Harwell, Windscale, and Calder. The opportunity was taken to send shift supervisors to the Harwell Reactor Training School. A series of lectures was given to the technical foremen by the professional staff in order to stimulate discussion about the problems to be faced in start-up and operation of the reactor.

To provide an objective for the time spent in the Design Office, the writing of a descriptive manual was undertaken. Besides ultimately providing a valuable work of reference, the searching out and presentation of the information ensured that the personnel acquired a good understanding of the equipment and were then in a position to specify operating instructions. Production of the descriptive manual was followed by an operational manual in which there were two sections. The first of these dealt with technical policy of operation, covering such items as organization, limits of operation and procedures. The second part of the operational manual comprised the detailed operational instructions for every item of plant. The value of the production of such manuals cannot be emphasized too strongly: they are time consuming to produce, but provide a sound basis for approaching operation of the plant.

COMMISSIONING

The fact that this reactor uses a liquid metal coolant from which the atmosphere had to be rigorously excluded introduced many novel problems, and much attention was paid to proving satisfactory functioning of equipment which would ultimately be associated with the liquid metal either during operations or maintenance. The commissioning was divided into four separate and distinct phases as follows:

Stage 1—Dry testing In this phase, the operation of all equipment was tested as far as possible in the way in which it would be used operationally but in the absence

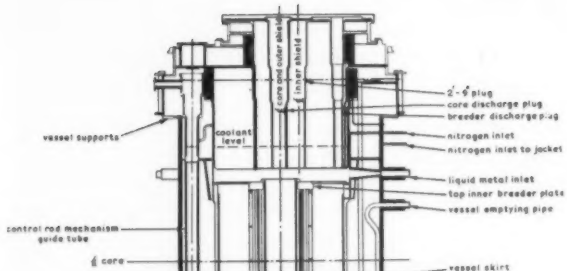


Diagram of reactor vessel shows position of access holes to core and breeder and to control unit mechanism tubes (Fig. 2)

of liquid metal. The initial natural uranium charge was loaded during this phase.

Stage 2—Liquid metal preparation and charging Partly overlapping Stage 1, the liquid metal charge—some 120 tons of 70/30 NaK alloy—was prepared and charged into the circuits.

Stage 3—Testing in liquid metal Those items of equipment which were ultimately to work in liquid metal were tried out in the liquid metal at this stage. Trial removals of equipment for maintenance purposes were also carried out.

Stage 4—Final approach The method adopted for critical assembly was basically that used for Zeus. Enriched uranium elements were exchanged one at a time for natural elements until criticality was achieved, and then the desired degree of super-criticality was added.

The principles of the commissioning programme were considered by a start-up working party under the chairmanship of myself as the Fast Reactor Project Manager, with representatives from the Fast Reactor Design Office, Risley, the Reactor Division, Harwell, Dounreay Engineering Division, Dounreay Health and Safety Division, Dounreay Fast Reactor Operations Group, and Dounreay Fast Reactor Technology Group.

STAGE 1—DRY TESTING

Preparation for charging

During operation mechanical seals are made between the reactor vessel and outer shield and between the outer and inner shields. Before charge/discharge operations can take place, these seals are broken after reducing the gas pressure from 50 lb/in² to 0·5 lb/in². This reduction in pressure is achieved by means of diaphragm type pumps which transfer the nitrogen from the vessel gas space and buffer vessels into shielded storage tanks. The blanket gas at 0·5 lb/in.² is retained in the vessel by mercury and mercury amalgam seals which permit rotation of the shields. Figure 2 indicates the positions of the access holes through the shields.

All the equipment is then stripped off the 2 ft 9 in. plug and an adaptor valve fastened onto and over this plug. Figure 3 shows this equipment in position but with no electrical or instrument connexion made. This valve contains a four-jaw clamp which is then operated to hold in the charge plug while the retaining bolts are removed. The charge plug flask is positioned onto the valve and the flask interior purged by successively pressurizing and exhausting to atmosphere with oxygen-free nitrogen which has been passed through a liquid metal scrubber to reduce the oxygen content to less than 10 parts per million. Purging is carried out until the oxygen level is less than 100 ppm. An electrically operated grab is then lowered from a winch in the flask and engaged in the charge plug top. The four-jaw clamp is opened and the plug withdrawn into the flask. After closing the adaptor valve to seal off the reactor, and closing the flask valve to maintain the plug in a nitrogen atmosphere, the flask is then removed.

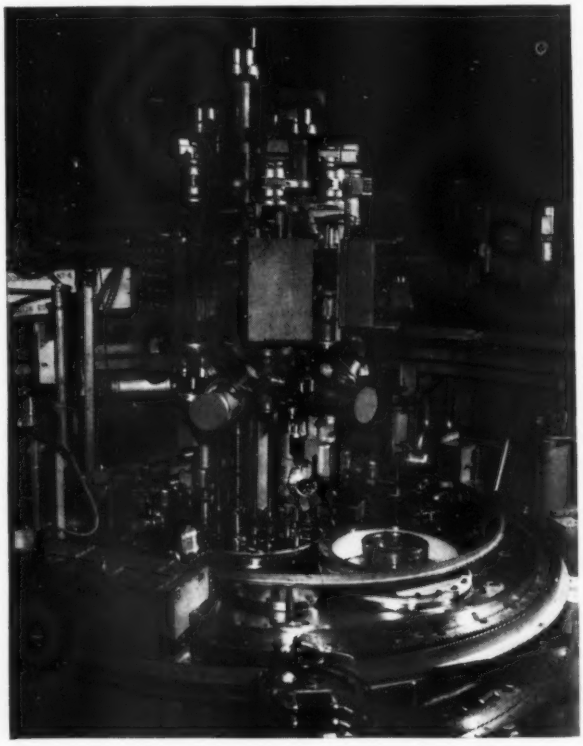
A similar procedure in reverse is used to insert the liner tube from the liner tube flask. This liner tube dips below the liquid metal surface and isolates the blanket gas, which will ultimately be active, from the charge machine.

Both the charge plug and liner tube flasks were tested mechanically and functionally in that they were operated as though liquid metal were present. Before these operations were satisfactorily carried out, minor modifications were necessary to provide freedom of movement of the grabs while ensuring correct alignment.

Fuel handling

Each new fuel element is placed in a lead lined, stainless steel can which is evacuated, nitrogen filled, and fitted with a rubber gasketed lid. The canned element is then fed, with up to 32 others, into the magazine of a canning station inside the sphere. The magazine compartment is then purged with nitrogen. From this magazine, the canned ele-

Operational equipment in position on 2 ft 9 in. plug. There are twelve position indicators for the control units, three boron rod machines, an oscillator, and a neutron source machine (Fig. 3)



ments are fed singly through a valve into a shielded trolley which can be turned from the horizontal position in which it received the element into the vertical position. The trolley is first traversed to a position where the lid is removed and then positioned beneath a valve on the top of the canning station.

The charge/discharge machine is placed on top of this valve and after appropriate nitrogen purging of the machine and the space between the valve and the valve on the bottom of the charge machine, both valves are opened and the charge machine snout lowered to pick up the element, leaving behind the lead lined can. The valves are then closed, and the charge machine moved away to be placed on the adaptor valve on the reactor from which position the element is lowered into the reactor, again with appropriate purging.

The rotating shields are then moved to the position corresponding to the next element to be removed. The charge machine picks up this element, cooling it with its own gas cooling equipment, returns with it to the canning station and places it inside the lead lined stainless steel can vacated by the previous element. The lid is re-inserted and brazed in position. The trolley is then traversed to another position from which the canned element is removed into a shielded transit flask for transport out of the sphere and to storage under water in the cooling pond. Figure 4 shows the canning station. The lead lining in the stainless steel can be partially melted by the residual heat production of the element (up to 2 kW). Before storage in the pond, the can is immersed in a molten lead bath to ensure complete melting of the inner lead sheath. This process ensures alloying of the lead with any NaK on the outside of the element and also provides a heat path for the transfer of the fission product heat to the cooling pond water.

Elements loaded by hand

Completion of the charge machine and canning station were two of the items which were outstanding at the official handover, and it was not possible immediately to carry out a full scale test on the complete operation as described. The charge machine became available first and extensive training of operators was carried out with the machine mounted over a dummy core. The machine was then used to load the natural uranium elements into the reactor core, feeding them into the machine by hand. Meanwhile the majority of the breeder elements had been loaded by hand. A sufficient number were left to be loaded later by the machine to confirm its satisfactory performance. When the canning station eventually became available, it was put through extensive trials by feeding elements through the magazine and removing them from the trolley through the top of the station.

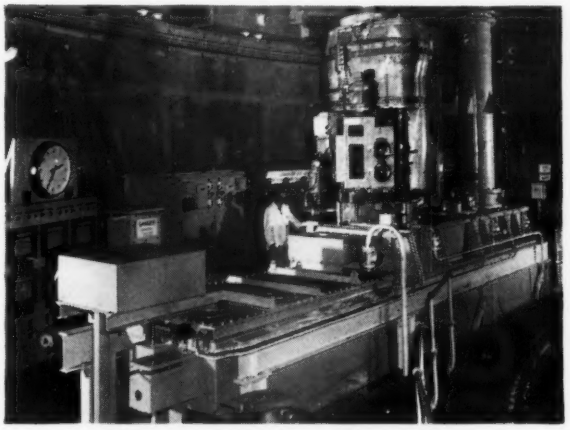
A considerable number of difficulties with charge machine and canning station were met and overcome by modifications as necessary. It was found necessary for instance to increase the accuracy of indication of the charge machine snout position with respect to the core.

Because of the dimensions it was not possible to station an observer inside the vessel to watch the behaviour of the machine when operating. It was considered imperative that such observation was obtained, and considerable use was made of a small TV camera which displayed a very satisfactory picture of the accuracy of location of the charge machine snout during loading.

Control rod maintenance

There are five main items to each of the twelve control units (see Figure 5): the mechanism which includes the rotax screw and nut assembly and the carrier supporting arm; the carrier (or control rod) which forms part of the core and contains 10 elements; the drive assembly which transmits the drive to the rotax screw through a diaphragm by means of a magnetic clutch; the electromagnet assemblies for drive and for hold-on; and the primary drive motor, gearbox and shaft. As these items may all require maintenance at some time, special equipment is provided for removing those parts which are normally in contact with the liquid metal or nitrogen blanket.

Basically, the equipment works on the same principles as described for removal of the charge plug and liner tube, namely that after suitable preparation of the access hole through which the unit works, the unit is held by a clamp during the removal of securing bolts and then with-



The magazine compartment is in the foreground, and the charge machine and a fuel unit transit flask are in position over the trolley compartment (Fig. 4)

drawn into a purged flask. Valves are then closed both to seal off the reactor and to seal the unit in its flask. This procedure applies in the case of the control rod carrier and the drive assembly. A separate flask operation is required to change the joint ring below the drive assembly. A similar procedure is also used to remove the control unit mechanism, but this operation is complicated somewhat in that the horizontal arm has to be lowered into the vertical position. This is accomplished by incorporation of a drive mechanism in the attachment gear, and at an appropriate point in the lift after lining up a drive shaft through the wall of the flask, operation of this mechanism lowers the arm.

In order to acquire experience in the removal of this rather complicated mechanism, and to prove that each of the units could be handled with the removal equipment provided, every one of the twelve units was removed and replaced using the equipment as though liquid metal were present. Satisfactory lowering of the horizontal arm was observed by use of the TV camera. This series of trials indicated the necessity for modifications to access facilities, remedial work on one of the control mechanisms to ensure satisfactory operation of the arm lowering mechanism, modifications to grabs for attachment to top hat

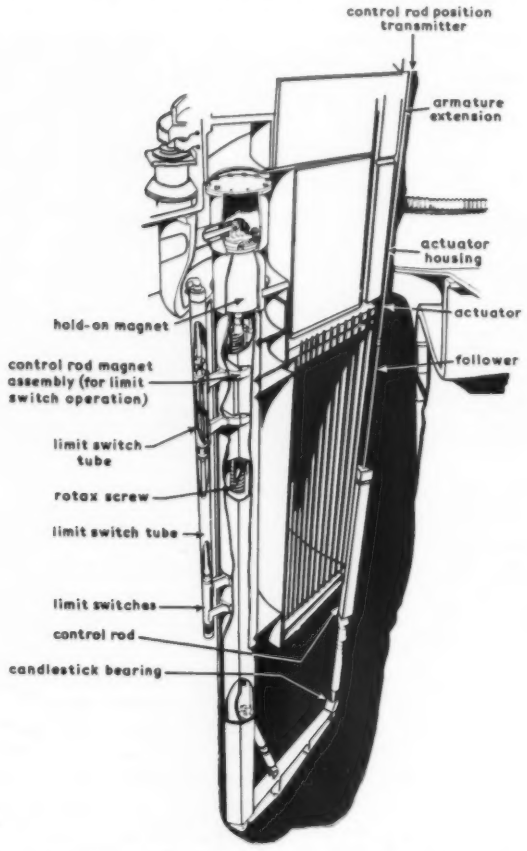
assemblies and various alterations to improve alignment during operation.

By this time full and ample justification had been demonstrated for the policy of complete functional dry testing of these items of equipment, despite the fact that all of it looked alright as individual pieces of equipment.

Observation points important

Similar equipment was provided and tested in the same fashion for removal of 'followers' (see Figure 5) which transmit movement of control unit carriers up to instrumentation normally mounted on the 2 ft 9 in. plug, thermocouples located in the liquid metal header beneath the core and blanket, vessel immersion heaters, and control rod limit switches in the rotating shields.

A total of six months was spent on the dry testing. This is about two months longer than would have been necessary if no delays had been occasioned by the late delivery



Arrangement of a control unit and mechanism (Fig. 5)

of certain items and late design modifications. The main lesson learned was the importance of providing as many facilities as possible for observing how operations were proceeding during movement of equipment which was out of sight because of shielding requirements. For example, windows were fitted to flasks to permit observations of the functioning of the winches; other windows were positioned to permit confirmation that the equipment was located accurately. A window was temporarily fitted to the side of the charge machine, and this was found to be so essential to satisfactory operation that a permanent installation is being designed to replace this facility when the activity of the system renders such direct methods impracticable. Most of the flasks have been supplied with motorized drives to the winches, but it was found that trouble with misalignment and non-operation of grabs could be felt by hand operation of the drives before damage was caused, and the few minutes saved by motorized operation was not considered to be worth the risk of the consequence of mal-operation of the equipment.

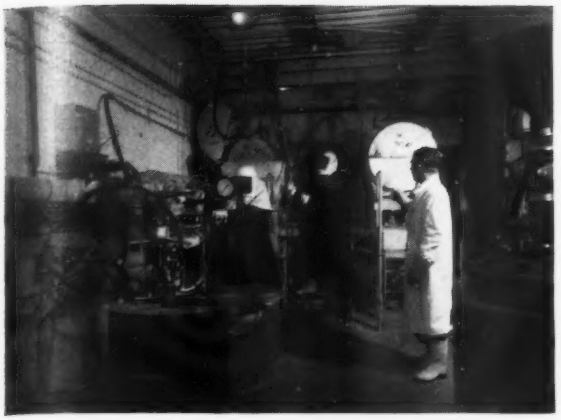
During the dry testing period, attention was also directed to determining points of leakage noted on the nitrogen buffer tanks in the construction pressure test. Pressurizing was accompanied by the introduction of nitrous oxide as a leak indicator. Leaks were discovered on the access covers to the tanks and rectification of these was continued until no leaks were detectable. It was considered that the circuits were sufficiently sound to take the next step, that of liquid metal filling. The presence of fission product activity at low levels in the early stages of operation will provide a sensitive tracer for further leak detection in the nitrogen circuits.

STAGE 2—METAL CHARGING

The liquid metal coolant used for the reactor primary and secondary circuits is a 70/30 NaK alloy which has a melting point of 40°C. The thermal syphon circuits are filled with the eutectic alloy, 22/78 NaK. The 70/30 alloy was made by mixing the available alloys of 50/50, 40/60, 22/78, together with pure sodium in the requisite proportions to produce the 51 tons required for the primary circuits, and 67 tons for the secondary circuits. The mixing was carried out in the liquid metal charging station. There the 1-cwt containers of alloy were heated in muff furnaces, and the metal transferred by means of nitrogen pressure to a collecting furnace and ultimately through filters to storage tanks. The sodium drums were heated in an elevated muff furnace, and the contents transferred by gravity to the collecting furnace. The various containers were emptied in such an order that approximately the correct proportions of sodium and potassium were maintained in the storage tanks. Figure 6 shows some of the equipment in the charge station.

All pipework and filters were trace heated and lagged so as to prevent sodium freezing. As can be seen, fully protective clothing was worn by operators who would be likely to come into contact with the liquid metal in the event of a spillage or leak. The entire operation of melting some 120 tons of liquid metal was accomplished with no more than one or two minor burns which were due to careless removal of protective clothing. Minor fires which occurred whenever alloy was exposed to the atmosphere were very readily extinguished by the application of dry powder.

The transfer of the molten alloy to the underground heated storage or dump tanks was carried out by means of pressurized nitrogen. There are eight of these tanks, six for the primary circuits and two for the secondaries. The six primary tanks are arranged in series and can contain the entire primary charge (see Figure 1). The two secondary dump tanks are also arranged in series and can contain the alloy from three secondary circuits. Before any liquid metal mixing was begun, pipework, vessels, dump tanks etc, were all purged, first with commercial nitrogen and then with oxygen-free nitrogen to a level of 30 ppm



Liquid metal preparation. In the left foreground is an alloy container surrounded by the muff furnace, and the operator at the back of the picture is locating a sodium drum in a muff (Fig. 6)

oxygen. Purging of the equipment began as soon as the plant was taken over, and the liquid metal melting began early in 1959. By the end of February the 51 tons for the primary circuit was available. Considerable difficulties were encountered due to the presence of large quantities of oxide in the alloy which had been stored for some time. This caused blockages in pipework bends and valves, and necessitated frequent changing of the filters. Clearing these blockages not only provided experience in the handling of liquid metal and decontamination of equipment which had been in contact with the metal, but also gave valuable indications as to where considerable improvements could be effected in design of plant for handling dirty liquid metal, for example, larger bore pipes, removable sections of lines where blocking is likely, right-angle bends with provision for rodding and the use of cocks instead of valves with tortuous paths.

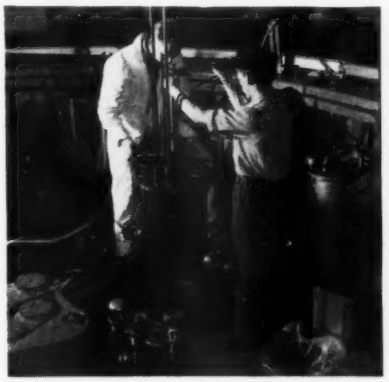
Final pressure test

By early June, the dry testing phase had been completed, the liquid metal primary charge was available in the dump tanks, and final preparations were made for the charging procedure. The equipment access hole to the vault containing the heat exchangers had been sealed up after a final inspection and space heating was switched on to bring the vault temperature up to 120°C. The reactor vessel 2 ft 9 in. plug was finally installed and equipment built up so as to prepare the primary circuit for its final pressure check. Figure 3 shows the equipment assembled on the plug for this test.

The circuit was purged with commercial nitrogen and then oxygen-free nitrogen, down to an oxygen content of 30 ppm and some 50 tons of NaK transferred by means of nitrogen at pressure from the dump tanks to the primary circuit. Some of the secondary circuits had already been filled in a similar manner and they were used to help heat up the primary circuit by transferring heat injected by means of factory steam into the secondary NaK/water heat exchangers. All space and trace heating was also in operation. The temperature of the liquid metal being charged was slightly lower than the circuit temperatures in order to prevent the deposition of oxide as the circuit was filled, and it was possible to follow the course of the filling operation by the temperature changes recorded by the installed thermocouples at different levels throughout the system as the liquid metal reached them. Eventually the liquid level was registered by the level gauges in the expansion tanks in the primary heat exchanger circuits (see Figure 1). A continuous check was also made on the amount of liquid metal removed from the dump tanks. The charging rate was about four tons per hour, and a filter in the filling line prevented any particulate oxide or debris entering the primary circuit. Considerable pains had been taken during construction and preparatory phases to keep these circuits very clean, as the presence of particulate matter could block the very fine coolant passages in the core. Moreover, because of the corrosive effects of sodium oxide in the alloy, every effort was made to minimize the amount of oxygen available for pick up by the liquid metal.

Operation of EM pumps

The liquid metal was circulated using the 24 primary electromagnetic pumps for 12 hours and then transferred back to the dump tanks, by-passing the filter. After cooling to 80°C and hence precipitation of a certain amount of oxide, the metal was then recharged again through filters into the primary circuits in the same manner as before. The solubility of oxide in liquid metal is very temperature dependent, a fact which is made use of in the facilities for oxide removal in the circuits, namely the cold



Special equipment developed to clean and free control units. A torque spanner is used to move the screw mechanism (Fig. 7)

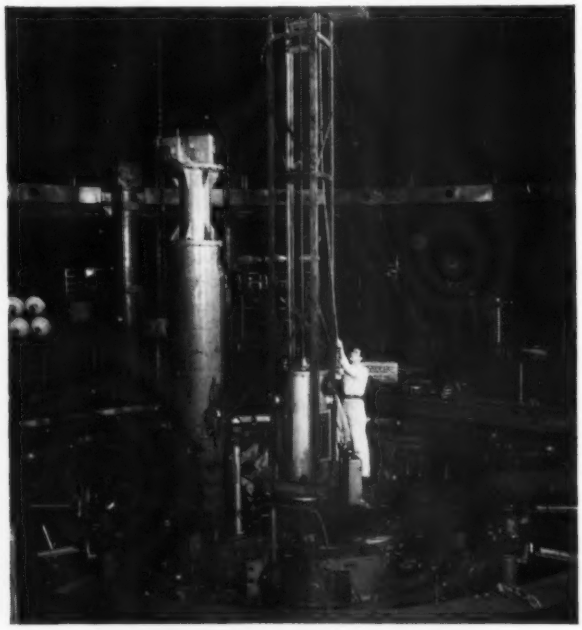
traps. The initial loading was carried out at 120°C so as to clean up the circuits as much as possible and because it was not possible to guarantee that there were not pockets in the dump tanks of unmixed Na which would have solidified at 98°C.

Once the liquid metal had been charged, all 24 primary pumps were operated continuously for five days during which time the behaviour of flowmeters, cooling systems and temperature instrumentation was observed. Initial tests were also carried out on the behaviour of the flow in individual primary circuits upon failure of pumps or of diesels supplying groups of pumps. The main purpose of the liquid metal circulation was to begin the coolant clean-up.

The importance of achieving and maintaining a very low oxygen content in the coolant has already been mentioned: corrosion of the fuel element materials will take place at operating temperatures corresponding to high powers if there are more than a few parts per million of oxygen

present in the liquid metal. Before these temperatures are reached, therefore, there are the two allied problems of achieving these low levels and of measuring them.

Each primary circuit contains a by-pass loop through which a few per cent of the main flow circulates (see Figure 1). On some of the circuits, part of this by-pass flow is cooled in a cold trap and the precipitated sodium oxide deposited upon the surface of the ring packing material. The liquid metal is heated in a regenerative heat exchanger before being returned to the main circuit. The extent to which these traps can remove oxide is dependent mainly upon the temperature to which the liquid metal is reduced, and about 20/30 ppm is about the lower limit. In order, however, to remove oxide down to a few ppm some of the circuit, by-passes are fitted with hot traps. In these liquid metal is passed over an extensive zirconium



The hand loading machine in use (Fig. 8)

surface at an elevated temperature, and the affinity of the zirconium for the oxygen at these temperatures results in its removal from the liquid metal.

The problem of determining when satisfactory low levels of oxygen have been achieved is a formidable one, and one of the circuits is to incorporate a meter which will measure the differential flow through two orifice plates, one of stainless steel and the other of niobium, the niobium plate being corroded to an extent dependent upon the oxide content of the liquid metal. A device for removing a sample of liquid metal, distilling off the sodium/potassium, and allowing chemical determination of the residual oxide is also being fabricated. At the time of liquid metal filling, however, neither of these facilities were available.

A meter based upon the fact that the resistivity of liquid metal changes with oxide content had been rapidly developed. Two of these meters were installed immediately prior to liquid metal charging. During the five days of circulation of coolant, flows were established in the cold trap circuits, and from previous experience with loop operations, the resistivity meters indicated that there was particular matter circulating in the coolant. Towards the end of June, the coolant circulation was reduced to the normal shut down value and the reactor prepared for the next phase, that of wet testing and completion of loading of the first charge.

STAGE 3—WET TESTING

Although the dry testing had been very extensive, it was considered essential to determine whether or not the presence of liquid metal unduly complicated the operation and maintenance of such items as the charge machine and control rods. Loading of the core and blanket had been left uncompleted in the dry state in order that some loading could be carried out at this stage.

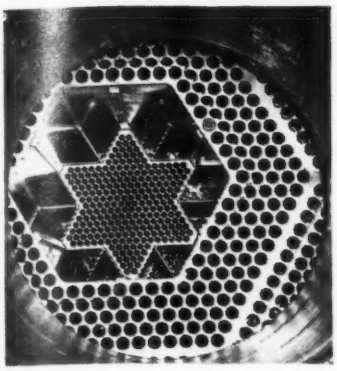
As every one of the control units had been removed during the dry testing trials, it was initially considered sufficient at this stage to remove and replace one only of the units. This operation was successfully carried out in a similar manner to that described in the dry testing stage, with the addition that appropriate purging was carried out in order to prevent access of air to the liquid metal surface. Upon replacement, however, a fault in the arm lowering mechanism was encountered and it was impossible immediately to replace the unit. It was therefore withdrawn again, and in order to free the flask for examination of the mechanism, the control unit was deposited in a container built specially for the purpose and of such construction that trial operation of the arm movement mechanism was possible before re-insertion in the reactor.

Loading of elements in fixed core positions was successfully carried out with the charge machine, but when attempts were made to operate the control units so that loading of the carriers could be completed, over half of the units could not be raised successfully. However, this in no way affected their shut-down function, which because of its different mode of operation, was in no way impaired. It was suspected, and subsequently confirmed, that an oxide scum on the liquid metal was interfering with free movement of the screw mechanism and bearings of the units, and it was decided further to clean up the liquid metal before any more attempts were made to move the control units.

Cleaning the coolant of oxide

Full-scale circulation of the coolant was resumed for eighteen days during which period a considerable quantity of oxide was apparently removed in the cold traps. Nevertheless, satisfactory operation of the control units was still not achieved. Special equipment was made to view the free liquid metal surface in a control unit position, and it was observed that there was an appreciable layer of oxide on the surface through which a thrust bearing and screw had to pass during the operation of the control unit. The viewing device was then developed so that by glove box techniques, a shaft could be engaged in the mechanism and the torque necessary to move it measured. Devices were also developed and used to skim the surface of the liquid metal and clean the jointing surfaces just above liquid metal level. The operations carried out were relatively simple in themselves, but complicated and prolonged by the need to maintain an oxygen-free atmosphere in contact with the liquid metal at all times.

These devices were used to clean the surface of the



View through the 2 ft 9 in. plug hole shows the fixed (star shaped) core top-plate and the 12 control unit carriers, all surrounded by the breeder top plate (Fig. 9)

liquid metal in each control unit tube and to free the screw and bearings. Figure 7 shows the device in position and a torque spanner being used to rotate the screw mechanism. In three cases, it was found necessary completely to remove the control unit mechanism and decontaminate from liquid metal before freedom of movement of the mechanism was obtained.

Although these troubles with the control units—being unexpected—introduced a delay into the commissioning programme, experience was gained which will be of great value when the added complication of activity in the liquid metal and mechanisms is encountered during maintenance and decontamination problems.

This phase of commissioning continued with the machine loading of the rest of the breeder elements, installation of a loop containing a plugging meter to measure oxide content, and further periods of full-scale coolant circulation in order to complete the clean-up of the coolant. Final setting up and testing of the instrumentation and automatic shut-down protection was carried out, and also testing of the system whereby the control units, i.e. safety rods, shut-down rods, boron rods, and control rods, must be operated in a particular sequence (see Sandiford's article, p. 100a).

STAGE 4—FINAL APPROACH

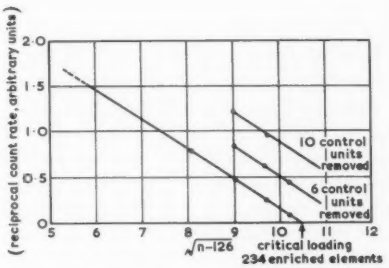
During the trials of the charge machine and canning station it was confirmed that the complicated procedure was rather time consuming. This was to be expected when it is remembered that the equipment was designed to handle highly irradiated material and all operations are remotely controlled. For the purposes of critical assembly where shielding was not essential, the main requirement was to prevent access of air to the liquid metal. A hand-loading machine was therefore designed and manufactured for this phase of operations. Figure 8 shows this machine in use.

The approach to criticality began with the core loaded with natural uranium elements. These were then replaced, one at a time, by elements of uranium of 45·5% enrichment. The expected final pattern of enriched and natural elements had been previously calculated, and this loading pattern was followed. The first elements to be interchanged were those in the control units, followed by those in the points of the fixed core star section (see Figure 9). The final phase of element interchange commenced from the centre and continued outwards.

The effects of this progressive enrichment of the core was observed on the appropriate section of the installed reactor instrumentation, viz: the low power instrumentation. There are three separate low power channels, each comprising a fission chamber and head amplifier, main amplifier, discriminator, scaler and reactivity meter (see Sandiford's article).

Each of the low power channels is connected into the reactor safety circuits so that a power in excess of that preselected (here, 100 watts) or a doubling time less than 20 seconds would cause a reactor shut-down, i.e. all the control units would be released to drop out of the core. There is 10 gramme radium/beryllium source installed which at low powers can be positioned near to the core, and provides a source of neutrons to enable the instrumentation to stay on scale even under shut-down conditions, i.e. when the effective reproduction factor is less than unity.

On October 28, critical assembly was started and after each interchange of elements the pulse count rate was accurately determined on the three low power channels. The results were plotted in the form of the now familiar approach curve, i.e. reciprocal count rate against a function of the number of enriched elements, n (see Figure 10). Towards the final stages of the assembly, the effectiveness of the various control unit groups was determined by lowering them from the core and determining the new count rate.



The approach to criticality as seen by one of the fission chamber channels. There are 126 elements in the control unit and points of the core star section, hence n represents the number of elements loaded on the final stage for core build-up (Fig. 10)

After 227 elements had been interchanged, the curves indicated that criticality would be achieved with a loading of 234 enriched fuel elements. The estimate upon which the loading pattern had been based was 235. A final interchange of 10 enriched elements was made. The three elements in excess of the 234 required for criticality would produce an excess reactivity of 0·5% which was adequate for the initial stages of operation. The reactor was then prepared for normal operation. The shut-down units were raised into the core and the control rods inserted in increments, taking count rates after each increment. In this way, the control rod position for criticality was predicted.

A final movement of the control rods was made which achieved criticality and put the reactor on to a 40 second doubling time at 10.52 a.m. on November 14, 1959. The power was levelled off at 30 watts.

Among those present to witness the occasion were Sir William Cook, Mr. P. T. Fletcher, Dr. Hurst, myself, Dr. W. Loewenstein of the USAEC, and Messrs. Shudko and Homeister of PRDC (Detroit).

DOUNREAY FAST REACTOR

Instrumentation and control

by K. R. SANDIFORD, B.Sc.(Eng.)
Chief Instrument Engineer, U.K.A.E.A., Risley

The use of liquid metal coolant, high temperatures, and the presence of the containment sphere poses special problems

ALTHOUGH THE INSTRUMENTATION of the Fast Reactor follows a similar general plan to that of the graphite-moderated natural uranium reactors at Calder Hall and Chapelcross, the special aspects of its mechanical design have presented a number of novel problems. These have required a considerable amount of experiment and design, both in the provision of instruments and in their installation. Features of the reactor which have presented special problems are the use of liquid metal coolant, the relatively high temperature (200°C) in which a number of the instruments have to operate, and the necessity of connecting the instrument cables through the containment sphere.

THE KEY MEASUREMENTS

NEUTRON FLUX
low power—logarithmic pulse counting channels
intermediate power—RC1 ionization chambers
high power—RC1 and RC2 chambers

COOLANT FLOW
magnetic flowmeters

COOLANT TEMPERATURE
thermocouples in pipe wall

As in the Calder Hall reactors, the main measurement for the control of the reactor is of neutron flux. In addition, provision is made for the measurement of rate of flow in each section of the coolant circuit and of a large number of temperatures associated with the coolant system. Similar measurements are made on the Calder Hall reactors but in the case of the Fast Reactor it is likely that considerably more use will be made of these measurements on the coolant circuit in the direct control of the reactor. The main measurement points are shown in Figure 1.

All instrument readings required for the control of the reactor are displayed in a control room adjacent to the reactor but outside the containment sphere. Most of the instruments are mounted on the control room panel arranged around three sides of the room, while the instruments and controls required directly by the reactor operator are mounted on a control desk from which the main instrument panel is also visible.

In addition to the indicating and recording instruments carried by the main instrument panel, the panel includes a glazed fronted section housing the relays associated with the safety circuit. It also carries a large number of conventional annunciator facias for the presentation of information from the general alarm and the safety circuits.

NEUTRON FLUX MEASUREMENTS

No special problems arise in connexion with neutron flux measurements on the Fast Reactor except that the temperature at the location of the sensitive elements is considerably higher than has been the case on previous reactors.

Although fission is produced by neutrons of high energy levels, the detectors used for the measurement of neutron flux are conventional devices sensitive to thermal neutrons. Fast neutrons from the core are thermalized in an equatorial belt of pure graphite contained within the borated graphite neutron shield. The neutron detectors are inserted into this thermal column through vertical holes which pass through the neutron shield (Figure 2).

The reactor has been designed to operate with a core power of 60 MW. To allow a reasonable margin on this figure, the instrumentation can cater for a maximum power of 100 MW. At 100 MW core power the neutron flux in the centre of the thermal column is estimated to be 2×10^{11} n/cm² sec. The shut-down power level with a neutron source inserted in the reactor will be about 50 MW. The range of power measurement is therefore milliwatts to 100 MW core power; the corresponding neutron flux range is from approximately 10^2 to 2×10^{11} n/cm² sec.

At shut-down the principal source of gamma radiation presented to the neutron detectors is that due to Na-24 in the reactor vessel. Experiments using mock sources suggest that this value is slightly greater than 100 röntgens per hour. Gamma radiation contributions from other sources,

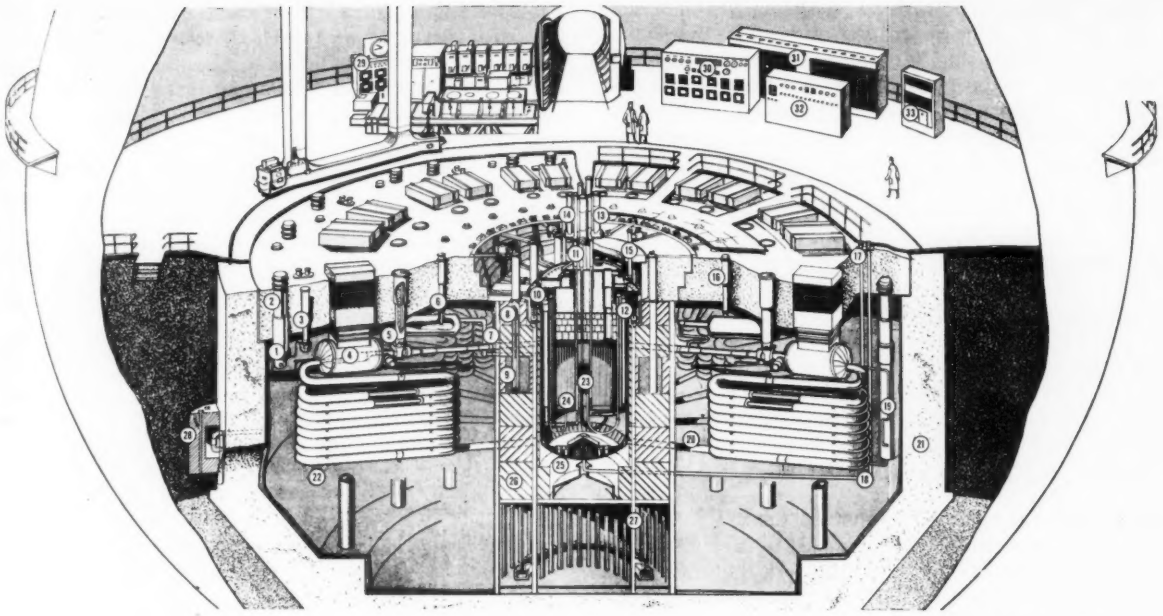


Fig. 1
Key to the main measurements made on the reactor shows:

1. Cold trap temperature
2. Cold trap heater temperature
3. Cold trap by-pass flowmeter
4. EM pump winding temperature
5. Main primary circuit flowmeter
6. LM level in expansion tank
7. Primary heat-exchanger outlet temperature
8. Nucleonic instrument
9. Nucleonic instrument tube temperature
10. Control rod motor temperature
11. Control rod position indicator
12. Control rod limit switch
13. Boron rod position indicator
14. Boron rod limit switch
15. Introscope (in position only at shut-down with concrete shield removed)
16. N_2 gas blanket pressure
17. Primary circuit leak detector
18. Vessel leak detector
19. Hot trap temperature control and heater overload thermocouples
20. Primary heat-exchanger inlet temperature
21. Temperatures in biological shield
22. Vault ambient temperature
23. Temperature under centre channel and core
24. Temperature under breeder
25. Temperature under vessel and at catchpot
26. Temperature in graphite
27. Vessel support temperature
28. Primary LM activity monitor
29. Hot trap cubicle
30. Sphere cubicle
31. Sphere rack
32. N_2 valve panel
33. Pile oscillator cabinet

including fission products, are negligible. To allow for experimental and other sources of error which may arise due to certain assumptions made when analysing the results of these experiments, a figure of 200 röntgens per hour has been taken as a reasonable value for the gamma radiation at each detector position. The use of 3 in. of lead shielding on any of the detectors will reduce this to approximately 10 röntgens per hour.

In order to provide measurement of neutron flux over the full power range of the reactor three groups of measuring equipment are required. These are respectively:

1. Low power—source level to 100 W
2. Intermediate power—2 W to 2 MW
3. High power—100 W to 100 MW

The low power equipment consists of three sets of logarithmic pulse counting channels operating from specially designed fission chambers with U-235 coatings. These chambers have a sensitivity of about one pulse per n/cm^2 sec. As they are relatively insensitive to gamma radiation no lead shielding is required.

For intermediate power measurement two sets of d.c. equipment are provided, each comprising an ionization chamber type RC1, and an associated period meter.

Four types of equipment are required for use at high operating power levels:

1. Multi-range linear power: 0 to 1 MW, 0 to 10 MW, 0 to 100 MW
2. Power drift: −2·5 MW, 0, + 2·5 MW and − 25 MW, 0, + 25 MW
3. Logarithmic power: 100 W to 100 MW
4. High power level trip: 1 MW to 100 MW

All high power channels except the logarithmic channel operate from ionization chambers type RC1, the logarithmic channel having the shorter type RC2.

To avoid irradiation damage and errors in measurement the low power and intermediate power detectors are retracted to a position of low neutron flux when their useful range has been exceeded, that is, when the high power instrumentation is on range. Retraction and insertion is effected from the control room by means of push buttons. An indication is available to the reactor operator of the positions occupied by these items. In the event of maloperation of the retraction controls, either during increasing or decreasing reactor power, an alarm is initiated in the control room.

At all times at least two instruments present a reading of pile power and its doubling time to the reactor operator. As a safety precaution a battery-operated indication of reactor power is also provided and this remains operative even in the event of a total failure of instrument power supply.

A 'clean' source of power supply is provided by motor alternator sets whose voltage and frequency are controlled within close limits. The power cables supplying each group of instruments are duplicated and run independently to avoid loss of measurements and reduce the risk of spurious trips. Alternative power supplies can be obtained quickly from either diesel alternators or the grid system.

Accuracy of power measurement

The total power developed in the reactor core is that due to fission rate plus fission product heating. If the

reactor has been operated for a substantial period at constant power level the fission product heating contribution will be approximately 6% of the total power. The nucleonic instrumentation provided does not measure this contribution: it measures fission rate only. At high power levels, where accurate power measurement is important, the detectors will be adjusted, as necessary, so that the indicated power level coincides with the true power level of the system. This adjustment will be made on the basis of a heat balance. At high powers it can then be assumed that the accuracy of power measurement will be better than $\pm$ 1%.

The accuracy of doubling time measurements will not be substantially affected by fission product activity but, because this measurement is presented as an inverse function of doubling time, the reading accuracy will vary over the range. For short doubling times, however, of the order of 20 seconds, it should be possible to achieve an accuracy of a few per cent.

Temperatures in nucleonic instrument tubes

The ion chambers need to be cooled to keep their temperatures down to a level at which they will operate satisfactorily. Cool air is circulated round the instrument tubes to keep the chambers at about 50°C; the graphite in which the detectors are installed operates at temperatures in excess of 200°C. The temperature at each detector is measured and presented on a 12-point potentiometric recorder, range 0–200°C, installed on a panel within the sphere. This recorder has high temperature alarm contacts connected into the general alarm system which operate if the temperature in any one of the instrument tubes exceeds 70°C. As a precaution, two separate cooling fans are provided and there are duplicate thermocouples at each of the three high power shut-down detectors. The thermocouples operate through magnetic amplifier relays to a duplicate alarm annunciator in the general alarm system.

The low power fission chambers, although cooled during normal operation, are designed to operate at elevated temperatures.

COOLANT CIRCUITS

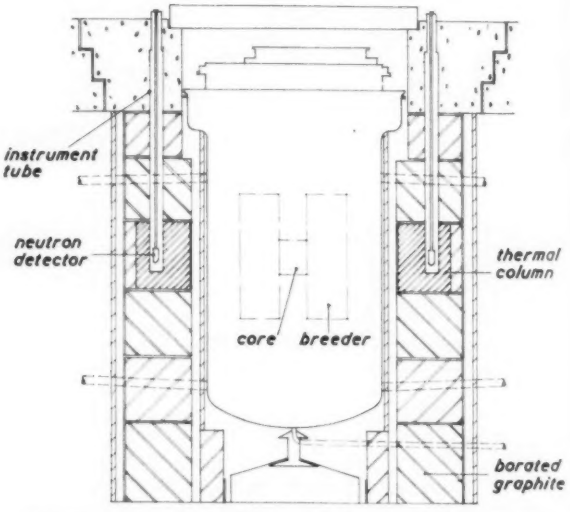
The principal measurements made on the liquid metal coolant circuits are the temperature of the coolant at the inlet and outlet of each heat exchanger, and the rate of liquid metal flow in each section of both the primary and the secondary coolant circuits.

In addition temperature measurements are made at the outlets of selected fuel element channels through the core and also at selected points below the breeder. These temperature measurements associated with the core are difficult to arrange as it is necessary to introduce the sensitive element as near as possible to the outlet of the appropriate channel to ensure that the measurement is representative of the channel temperature and is not influenced by mixing of the coolant with that from other channels.

Liquid metal flow

Flow measurements in the coolant circuits use the principle of a simple d.c. generator. A permanent magnet, of horse-shoe shape, is mounted directly on the pipework and accurately positioned so that the axis of the pipe is at right angles to the magnetic field and is midway between the two poles. As the liquid metal flowing in the pipe cuts the lines of force at right angles an e.m.f. is generated which is picked off on two electrodes welded to the pipe, the line joining the electrodes being at right angles to both the axis of this pipe and the magnetic flux axis. The stainless steel pipe attenuates the flowmeter signal but this effect is not significant. The coolant can therefore be considered as a solid conductor moved in one direction across the magnetic field. The e.m.f. generated is proportional to the rate of cutting of lines of force, that is to the velocity of the liquid metal in the pipe, and also to the diameter of the pipe. It is therefore necessary for the flowmeter to incorporate a measuring section in which the bore is machined to close limits.

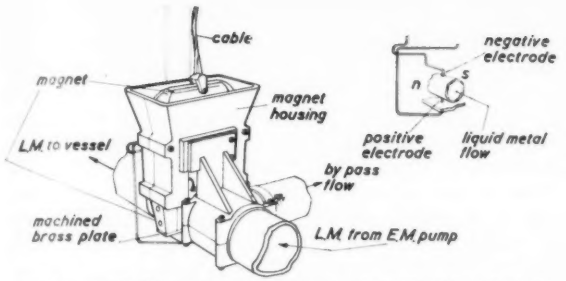
The mounting of the permanent magnet on the pipe and arrangement of the contacts is shown in Figure 3, which illustrates the main 4-in. flowmeter. Other flowmeters such as those in the by-pass circuits, follow a similar arrangement. The magnet housing is a brass casting machined prior to installation so that the magnet is accurately located in the required position on the coolant pipe.



Neutron flux measurements in the Fast Reactor are made after the neutrons have been thermalized. Conventional thermal devices are inserted vertically into a belt of pure graphite contained within the borated graphite shield (Fig. 2)

Since the flowmeters in the primary liquid metal circuits are located inside the biological shield, the electrodes are extended by rods welded to the electrode studs. These studs and extension rods are made of stainless steel, the same material as the pipes, to prevent thermo-electric effects. The rods pass through and are embedded in a concrete plug which acts as a radiation shield against the active liquid metal. The plug is made in two sections, one of which can be removed to allow the insertion of the flowmeter magnet into its housing by means of a cable winch. Brass guide boxes are used to steer the magnet into the required position. The electrodes pass through the fixed section of the plug and terminate in a junction box on the vault roof. Since concrete is a poor insulator each rod is covered by insulating sleeving for the full depth of the biological shield.

The magnets used in the primary liquid metal circuit flow measurements are *Calumax* magnets with a field strength of about 1000 gauss in a 4 in. gap. All magnets



Liquid metal flowmeters operate on the principle of the d.c. generator. A horseshoe magnet is placed across the pipe and the e.m.f. generated is picked up by two electrodes welded to the pipe as shown (Fig. 3)

used are stabilized and can be removed and replaced without the need for a keeper. The voltage output obtained across the electrodes at full coolant flow is 30 mV. Three different types of indicator are used and the voltage from each flowmeter is fed to the following points:

1. Direct to a potentiometric indicator, calibrated in lb/h on a linear scale and located on the control-room graphic panel
2. To a group of four summating magnetic amplifiers and thence to summated flow indicators and recorders in the control room
3. To a second group of summating magnetic amplifiers arranged to feed either into the alarm circuits in the control room or into a multiplying circuit; here the reading is combined with a derived value of temperature difference to give an indication of thermal power in the reactor core and breeder.

Liquid metal temperature measurement

To check the operation of the primary heat exchangers it is necessary to have an accurate determination of temperature at the inlet and outlet of each heat-exchanger system. Stainless steel-sheathed thermocouples of nickel-chrome/nickel-aluminium are used as detecting elements, inserted through guide tubes from the top of the biological shield into a special thermometer pocket machined in the pipe wall (Figure 4). A small section of the pipe incorporates the thermometer pocket and, as it is not leak jacketed, it is machined from solid stainless steel bar as a precaution against failure. Twin pockets, each fitted to a thermocouple guide tube, are provided at each point of measurement. To reduce the temperature gradient through the portion of pipe carrying these pockets, and hence the error in the temperature measurement, the section is fitted with thermal lagging which also extends over a small portion of the thermocouple guide tubes. A small quantity of powdered material of good thermal conductivity is introduced into the pocket to improve the thermal response time of the measurement.

An indication of the inlet and outlet temperatures associated with each of the heat-exchanger systems is presented on electronic-type potentiometric indicators fitted on the graphic panel in the reactor control room.

CONTROL SYSTEM

Reactor power is controlled by twelve mobile fuel-element rods inserted into the edge of the core from below, and three boron rods dropped into the inner ring of breeder elements at shut-down. All the operating mechanisms are controlled electrically from the reactor control room. The mechanisms for the fuel-element rods are identical but differ from those employed for the boron rods.

The fuel-element rods, although identical, are divided into three main groups, according to function:

1. Two safety rods, used to prevent the reactor from diverging during planned shut-down when fuelling is proceeding
2. Four shut-off rods, raised to the top position in the core and held there during normal operation; at shut-down they are dropped out of the core
3. Six control rods, moved together into or out of the core, about a position corresponding to criticality, to produce and maintain the desired operating power level; at shut-down they are lowered or dropped out of the core.

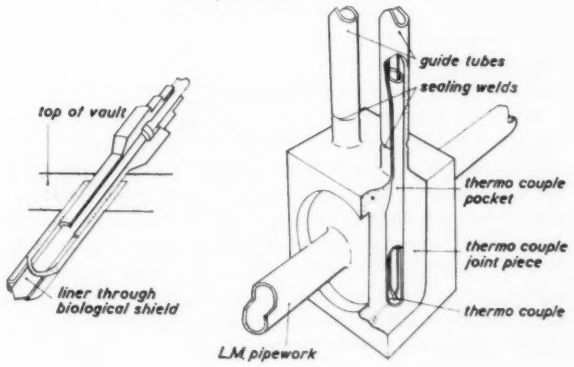
The boron rods provide a separate and independent means of reducing the reactivity in the core. In normal operation they are held up out of the core and are dropped into the core at shut-down.

Operation through electrical interlock

For reactor safety it is essential that the groups of control elements are operated in sequence during start-up or shut-down, and for this reason their operation is controlled by an electrical interlock system whose final contacts control the energizing supplies to the drive motors for the mechanisms. The rods are motored into the core at a speed of 0·003 in./sec and can be motored out at speeds of 0·003 or 0·15 in./sec. The fast speed is obtained by a solenoid-operated clutch in the rod driving mechanism which is engaged when this speed is selected. Fast speed cannot be engaged when the rods are being motored into the core and the solenoid clutch is mechanically biased to the lower speed to guard against failure of the solenoid.

The speed of insertion was chosen to keep the rate of reactivity insertion into the core to a maximum safe limit, on the assumption that all twelve elements might move in together. Normally the maximum rate of reactivity insertion will be obtained by moving in the six control rods as a group giving half the maximum permissible rate. Fine control is achieved by adjusting one rod. All six control rods are then trimmed to avoid non-uniform burnup in the core and asymmetric liquid-metal flow distribution in the core. In an emergency all fifteen control elements

Temperatures at the inlet and outlet of the heat exchangers are measured by a sheathed thermocouple inserted into a special pocket in the pipe wall. The whole pipe section is machined from a solid stainless steel bar to ensure that no leakage occurs (Fig. 4)



are dropped automatically by the trip circuits but an emergency shut-down button for manual operation, should it be necessary at any time, is also provided on the control desk. The number of controls has been reduced to a minimum to avoid unnecessary complications.

Individual fuel-element rods may be controlled independently and this facility is also used for testing, and for element discharge or replacement when the reactor is shut down. The boron rods can only be operated as a group. The positions of the control, shut-off and boron rods are monitored continuously by position indicators in the reactor control room. The position indicators are electrically connected to position transmitters at the tops of the rods. Extremities of travel are indicated, for each fuel-element rod, by lamp indicators in the control room, and indicator lamps also light when the boron rods are fully out. The limit switches for this are magnetically operated to control the operating sequence through the interlock system.

Control and shut-off rod position indicators

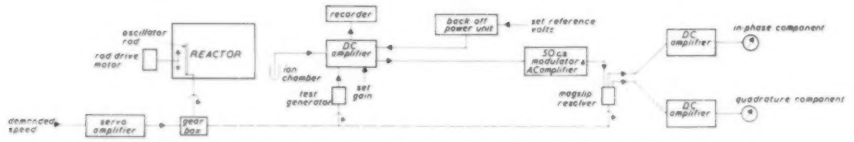
Attached to each of the six control and four shut-off rods is an electromagnetic device which follows the movement of the rod. An iron armature is moved inside its sealed housing in accordance with the movement of the corresponding control or shut-off rod. The position of the armature is detected by the control rod position transmitter placed over the housing. The transmitter circuit consists basically of a servo-operated inductance bridge whose two search coils are balanced by a fixed resistance potentiometer. The position of the coil assembly, which can move vertically over a distance of approximatey 30 in., is controlled by a screw and nut: the nut is fixed to the coil assembly and the screw is driven by a servo-motor controlled by a phase-sensitive amplifier. As the rod moves, the position of the armature alters, producing an out-of-balance signal from the bridge. This is fed via the amplifier to the servo-motor which restores electrical balance by moving the coil assembly so that the armature is mid-way between the two coils. The coil assembly will find any given position of the armature to within approximately 0·005 in. A magslip driven from the servo-motor shaft transmits any movement to the indicator in the control room, providing a continuous indication of control rod position.

If, due to sudden movement of the control rod or following a failure in the instrument power supply system, the position transmitter coils are not in step with the armature, a signal is automatically introduced at the input to the phase-sensitive servo amplifier and the coils are driven in an upward direction. The direction of scan is reversed at the top end of the transmitter travel if the iron armature has not come within the field of the coils, and scanning continues until the armature is reached. The time taken for the coil assembly to complete a single stroke is approximately three minutes.

TRANSFER FUNCTION ANALYSER

Permanently installed equipment is provided for the study of the dynamic response of the reactor under any condition of operation. A system of frequency analysis is adopted by means of which the reactor power is varied slightly from a steady state, employing an input perturbation which is sinusoidal with respect to time. The power level of the reactor is modulated by an absorber of low reactivity investment which is driven at fixed speeds within a frequency range of 0·002 to 3 c/s. The power response measured by neutron detectors can then be used to represent the reactor transfer function. Information provided by the analyser is in a form suitable for constructing Nyquist diagrams or phase/frequency and amplitude/frequency response characteristics. The equipment is designed to operate over a range of reactor power from 1 kW to 100 MW. Figure 5 shows the principle of operation of the instrument. Reactivity perturbation is achieved by rotating a control element containing a 'Dee' shaped absorber at the edge of the reactor core. Provision is also made for adjusting the rod axially to obtain the desired amplitude of modulation. Both rod speed and axial are controlled from the reactor control room.

The neutron flux variations are detected by an ionization chamber located in the thermal column, and its position may be adjusted remotely. Due to the low operating



The reactor's dynamic response under any conditions of operation can be studied by a permanently installed transfer function analyser (Fig. 5)

frequencies required, it is practicable to use a 50 c/s fundamental carrier frequency and the carrier modulators and demodulators take the form of simple synchronous converters which work at 50 c/s. Most of the signal information is contained in the fundamental 50 c/s carrier sidebands but harmonics resulting from square wave modulation also contribute without causing error.

Chopper stabilized d.c. amplifiers are used for the ion chamber current, recorder output, and for the in-phase and quadrature channel amplifiers. A reference generator, coupled to the rod drive mechanism, can be switched in place of the ion chamber and provides an in-phase and quadrature output for checking the correct operation of the resolving circuits. In operation the ion chamber and oscillator rod positions are set according to the reactor power level. The range of the ion chamber d.c. amplifier is then chosen to give about 0·5 volts d.c. output and this is backed-off using the reference supply unit. The resultant output is recorded at the reactor control desk on a linear recorder and is used by the reactor operator to maintain the correct power balance. The a.c. amplifier gain is selected to suit the level of modulation after which readings may be taken from the in-phase and quadrature channel indicators. During an oscillator experiment reversal of the rod will be necessary, and to avoid a transient excursion of reactor power the control circuits ensure that such reversals occur at the maximum perturbation position of the rod. On completing an experiment the rod is arranged to stop at a position of minimum perturbation.

High pressure water loop in Dido

by I. EVERSON B.Sc., A.M.I.Mech.E.
Senior Engineer, A.E.R.E., Harwell

The first of its kind in the UK, this recently commissioned facility at Harwell will be used for PWR research, particularly on marine reactors. Tests under operational conditions of pressure, temperature and radiation will cover heat transfer, burnup, corrosion of structural materials and coolant chemistry

UP TO THE PRESENT TIME most nuclear-powered ships have had pressurized-water reactors to raise steam for subsequent use in turbines driving the propellers. While the bulk of data required for designing such reactors is now readily available, some can best be established by experiment. This includes fuel element heat transfer, the relationship between burnup and fuel element life, corrosion of fuel-element canning materials and other structural materials under operational conditions, radiation damage to structural materials, and the chemistry of high-pressure, high-temperature water under radiation.

These experiments can conveniently be done using reactor test loops. A loop consists essentially of a closed circuit containing the proposed reactor working fluid at temperature and pressure. Means are provided for circulating this fluid at the correct velocities in critical sections to simulate reactor conditions. Fuel elements may or may not be incorporated, as required. One part of the loop, the in-pile section, is mounted in an experimental hole of a research reactor to subject selected items of equipment to a radiation intensity comparable with that expected in the proposed reactor. Fuel elements, if required, would be installed in the in-pile section.

A high-pressure water loop of this type has been constructed and installed recently in the Dido reactor building; the in-pile section is mounted in a vertical high-flux experimental hole. Operation under active conditions has started, and to date the loop has performed very satisfactorily.

REACTOR INSTALLATION

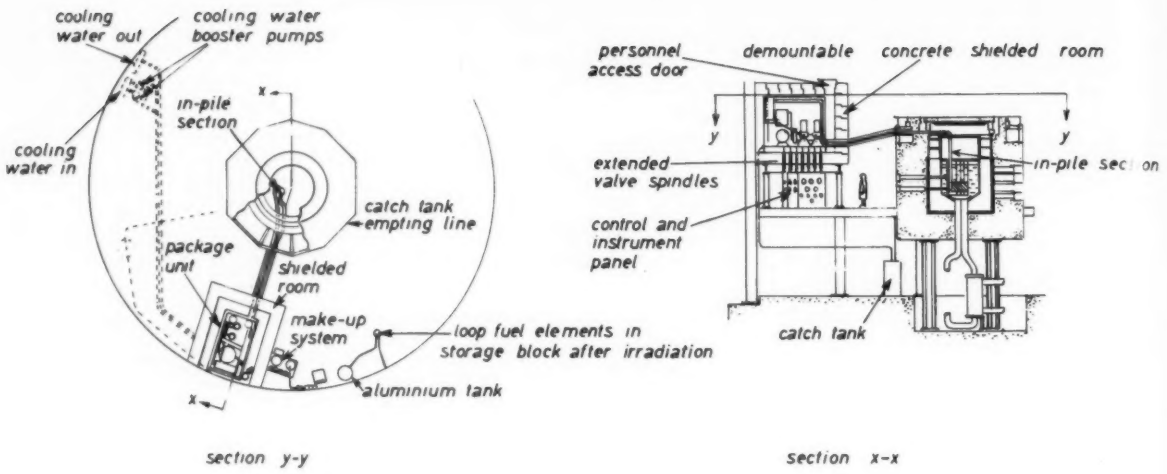
The location of the loop relative to the reactor is illustrated in Figure 1. A simplified flowsheet is given in Figure 2. Two Westinghouse A-150-D1 canned-rotor-and-stator pumps circulate water at rates up to 25 gal/min at 2000 lb/in² abs and temperatures up to 300°C. The main circuit consists mainly of 1·9 in. o.d. by 1·338 in. i.d. mild-steel piping, and the sampling/purification circuit consist mainly of 18/8/1 and 18/12/1 stainless-steel piping.

It will be seen that the main circuit comprises the in-pile test section, control test section, cooler, and heater. The in-pile test section houses the fuel elements being tested, together with steel specimens undergoing corrosion and radiation-damage tests, and is the only part of the loop subjected to intense reactor radiation. This is the most critical part of the loop, and special attention was paid to its design and manufacture. Further corrosion specimens are mounted in the control test section where flow conditions are similar to those in the inpile test section; this enables corrosion effects to be separated from radiation effects. A somewhat unusual cooler design was used, in which the high-pressure water transfers heat to water at atmospheric pressure, which then boils. The steam evolved is condensed in a water-cooled condenser. By using high boiling and condensing heat-transfer coefficients the size of cooler is minimized. Electric heating is required to maintain the loop temperature in the absence of nuclear heat. The main loop heater for this purpose is made in twelve sections, each consisting of a number of heater rods cast into aluminium blocks, around sections of the main circuit.

Since the loop is constructed largely of mild steel, it is important to maintain the water at a pH of about 10·5 in order to minimize corrosion. This is effected by means of ion-exchange resins in two mild-steel pressure vessels in a by-pass circuit called the sampling/purification circuit. In addition, sampling points are required for checking water conditions. These are connected to the same circuit, and to eliminate health hazards in taking samples, the sampling points are housed in a sealed structure, called the sampling drybox, consisting mainly of a mild-steel framework carrying Perspex panels. The chemist taking samples uses special long rubber gloves attached to the front Perspex panel to operate the valves. To eliminate ingestion health hazards when sampling, the dry box is kept permanently under a slight depression so that any leakage from the parts of the loop inside the drybox is prevented from escaping into the reactor building.

Demineralized water is boiled under 28 in. Hg vacuum to remove dissolved gases and is then pumped through two stainless-steel vessels containing the necessary ion-exchange resins to achieve the required conditions. The make-up pump is controlled automatically to maintain the quantity of water in the loop.

Pressure is generated in a mild-steel vessel, called the surge tank, which is connected to the loop by a permanently open pipe. This vessel is provided with four elec-



The in-pile section of the loop is installed in a vertical high-flux hole in Dido. The majority of the out-of-pile equipment is mounted in a rigid steel framework to form a packaged unit (Fig. 1)

tric heaters similar to the main-loop heater sections. Water in the surge tank is kept boiling and a switch connected to this vessel switches the heaters on and off to maintain the required pressure. Provision is made to enable the loop water to be degassed or alternatively to re-adsorb gases collecting in the surge-tank.

Numerous vent and drain points are provided to facilitate starting up and emptying of the loop. These are connected to separate vent and drain manifolds, each provided with an isolating valve to minimize leakage. The loop can be drained into a shielded stainless-steel catch tank on the ground floor of the reactor building.

Measurements and safety

Temperatures, pressures, flow rates, water levels and water conductivity are continuously measured and the more important parameters recorded. Comprehensive safety circuitry is provided to detect faulty operating conditions and to give alarms or trips as required. The main-circuit water activity is continuously monitored; any abnormal activity increase would indicate that a fuel-element sheath had ruptured. Serious loop malfunctioning would trip the loop heaters and pumps and ultimately the reactor itself. Provision is made for automatic loop blow-down under certain conditions into a tank containing sufficient cold water to prevent flashing to steam.

To facilitate installation and to make the best use of the limited space, as much as possible of the potentially active out-of-pile equipment was installed in a rigid steel framework, the entire unit being referred to as the package unit.

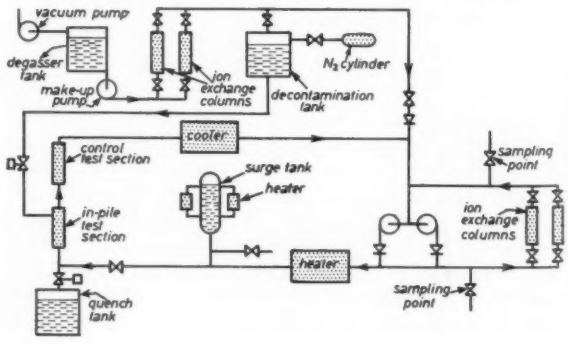
Since in operation parts of the loop become active, all potentially radioactive components are housed in a concrete shielded room with walls 2 feet thick or are surrounded by lead or steel of required thickness. As in the case of the drybox, the shielded room is kept under a slight depression. The make-up unit and the control and instrument panel are outside the shielded room. All important valves can be operated from outside the shielded room in complete safety.

The bulk of the make-up system is in the form of two sub-assemblies installed on a steel structure adjoining the shielded room, while the makeup pump is located on the ground floor of the reactor building some 30 feet below the degasser tank. This is done to ensure that the suction head is always positive to prevent air from being sucked into the makeup pump, entering the main circuit via the makeup water, and thereby causing corrosion.

To prevent serious overheating of the loop fuel elements, cooling-water circulation is required even when the reactor is shut down. Means are provided for ensuring adequate flow even if the loop pumps fail. Emergency cooling water is stored in a stainless-steel tank under a nitrogen atmosphere at about 100 lb/in^2. Under the requisite fault conditions this water is forced directly into the in-pile test section to provide the fuel-element cooling.

Heavily shielded vessels are required for loading and unloading fuel elements from the in-pile test section to protect personnel from radiation hazards. After unloading from the in-pile test section, the irradiated fuel elements are stored temporarily in the reactor storage block in a special assembly. Water cooling required to prevent overheating is supplied from an aluminium tank mounted adjacent to the shielded room. This special assembly together with the irradiated fuel elements can subsequently

The main loop circuit comprises the in-pile test section, control test section, cooler and heater (Fig. 2)



be transferred to the Active Handling Building where special equipment is installed to permit radiography of the fuel elements and to examine them by remote-handling equipment.

Babcock & Wilcox Ltd. was appointed the main contractor and undertook the detailed design and manufacture of the bulk of the loop. The shielded room was designed by the Ministry of Works and manufactured by Chivers Ltd., and the various steel work associated with the loop was designed and manufactured by Whessoe Ltd. Lloyd's Register of Shipping was appointed as the inspection authority on behalf of the UKAEA, and all high-pressure components were made under Lloyds' survey.

DESIGN AND CONSTRUCTION

Leak rate reduction

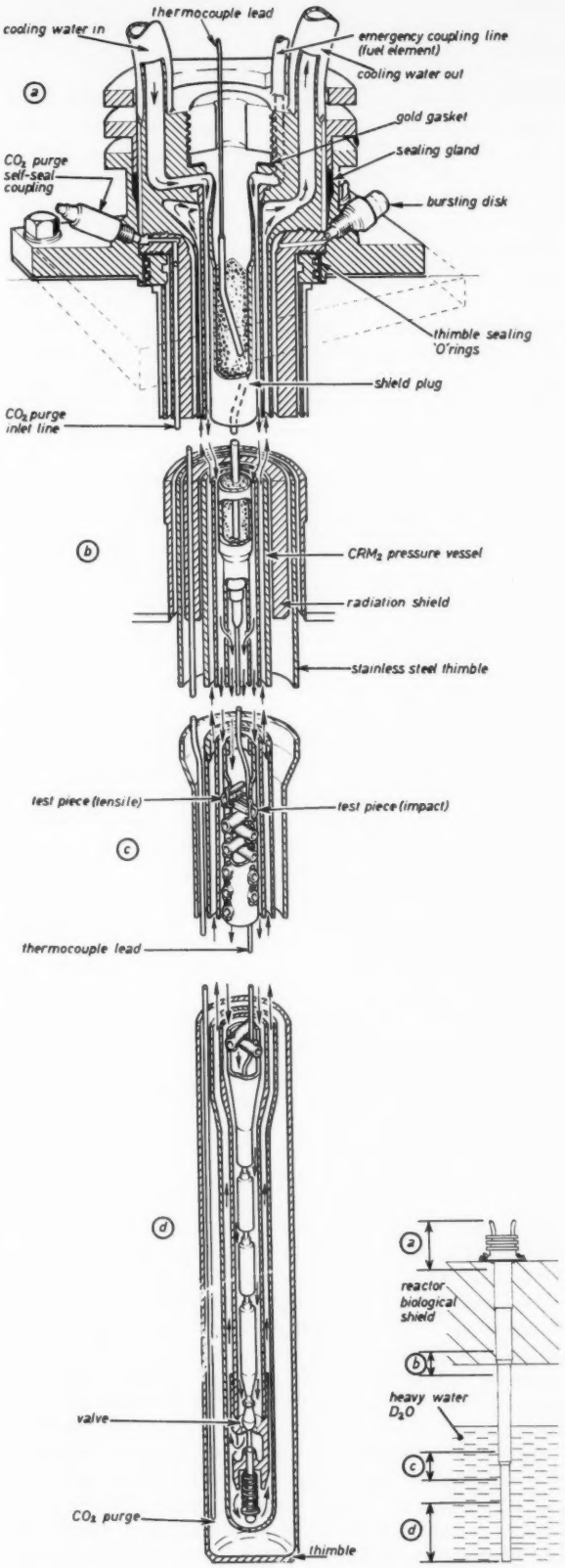
It is very important to reduce leakage from this loop to a minimum, for both scientific and health reasons: an excessive leak rate would vitiate the chemical results, and water contained in the loop, when operating under active conditions, is radioactive. Experience on other loops suggested that it would be possible to reduce the leak rate to a few hundred grams per day, albeit at the cost of extraordinary care during construction, assembly and operation. It was decided in the present case to aim for a leak rate of 1–2 kg/day since even at this higher value chemical results could be sufficiently intelligibly interpreted. Every effort will of course be made to reduce the leak rate still further.

In order to achieve these low rates special methods of leak detection are necessary. The use of crude methods such as mirrors to condense steam escaping from leaks could result in the reduction of the total rate only to about 10 kg/day before the limits of detection were reached. A more sensitive method for leak detection uses a hygrometer in which a known air flow is induced through a probe which is used to check all possible leak points. Leakage of steam results in the local atmosphere having an increased humidity which is detected by this equipment. A device of this type can be made sufficiently sensitive to detect leakage from a weld which would be regarded as perfect according to visual and radiographic examination and pressure testing. A survey of this sort followed by the appropriate rectifications could result in the reduction of the leak rate from a loop of this type and dimensions to 100–200 g/day.

Welding precautions

Previous experience suggested that low leak rates would be most readily achieved by using welded joints wherever possible. Mechanical joints are therefore only used for components which need to be demountable for ease of replacement or servicing e.g. pumps and differential-pressure cells.

While it is customary in all reputable welding firms to subject welders to rigorous testing to demonstrate their competence before starting a particular job, it was felt that even greater care should be taken in this case. All welders were required to satisfy the inspection authority of their competence before being allowed to start welding on this loop. All test welds simulated, as closely as possible, the anticipated environmental difficulties of the actual welds in the loop. Test pieces, after welding, were radiographed and a proportion were cut into longitudinal



Contained in the in-pile section and subjected to intense radiation are the test fuel elements and steel specimens undergoing corrosion and radiation-damage tests under simulated PWR conditions of flow, temperature and pressure. Total length of the section is 11 ft, diameter of the pressure head 9 in. (Fig. 3)

strips which were subsequently given direct and reverse-bend, tensile, and impact, tests in order to establish the relationship between the radiographs and the standard of welding. Only when all tests were satisfactorily completed was the welder in question allowed to work on the loop itself. Welders were retested before working on site even if they had been previously cleared for shop welding. The contractors were required to agree the design of all high-pressure components with the inspection authority and where necessary to develop or modify welding techniques.

All pressure welds were radiographed which showed that the extraordinary precautions taken were fully justified in that on the radiographic evidence less than 1% of the welds had to be remade.

In-pile test section

This component, the most critical feature of the loop, is illustrated in Figure 3. It is desirable from heat transfer, corrosion, and fuel-element testing considerations to ensure that the loop fuel elements operate at least at the same heat flux as that proposed for the reactor. This implies that the loop fuel elements should be subjected to the same thermal-neutron flux as those in the full-size reactor, since it is not feasible to make the loop fuel elements more highly enriched than the reactor fuel elements.

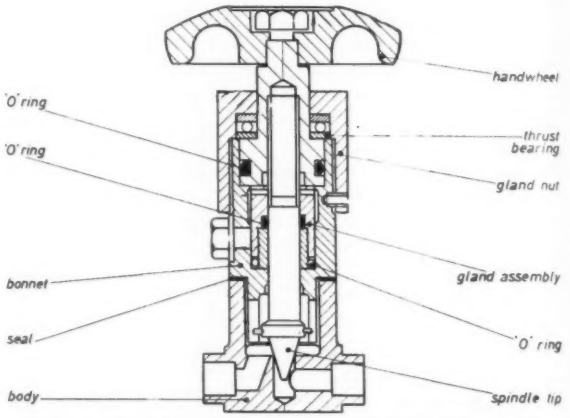
The thermal-neutron flux in the immediate vicinity of the loop fuel elements is of necessity less than that immediately outside the experimental hole, largely because of absorption of neutrons by the constructional materials of the in-pile section, and to a secondary extent because of streaming losses.

The pressure-vessel bore was made as small as possible and the wall as thin as possible consistent with safety to reduce this neutron-flux depression. However, even with these precautions the loop fuel elements are exposed to a thermal-neutron flux somewhat less than that expected in the full-size reactor. Consequently the expected heat flux will be correspondingly less than that in the full-size reactor, so that to achieve the same degree of burnup the loop fuel elements must be operated for a correspondingly longer period.

Because of the requirement for using the minimum wall thickness it became necessary to stress the vessel as highly as possible. Proper allowances were made for thermal stresses arising from temperature differences due to the presence of the high-temperature loop water and nuclear heat generation in the vessel walls caused by the reactor radiation. It was finally decided that the maximum hoop stress should not exceed 50% of the yield value. Stresses of this magnitude are in excess of those recommended by current standard codes of practice (BS 1500 and API-ASME), but in this decision due regard was paid to the facts that inspection was much more rigorous than that recommended by these codes of practice and that the expected life of the vessel is no more than 2–3 years.

An uncertainty arose because of the phenomenon of embrittlement induced in low-alloy steels by reactor radiation. This embrittlement is known to be a function of the initial metallurgical state of the steel and is a complex matter. Means are therefore provided for irradiating steel specimens made from the same material as the pressure-vessel wall. These will be removed and tested from time to time after being subjected to progressively increasing radiation doses.

When the loop pressure vessel was being designed it had been decided to construct the reactor pressure vessel of a Cr-Mo steel not precisely specified at that time. It was therefore decided that the loop vessel should also be made of a Cr-Mo steel. Available experience and theoretical knowledge suggested that the best commercial Cr-Mo steel to use contains 2¼% Cr and 1% Mo. This steel is known to have considerable resistance to radiation damage and its metallurgy is well understood since it has long been used for steam piping. It was accordingly used for the pressure-vessel body, while the vessel head, which is not subjected to intense radiation, was made from boiler-quality mild steel, which has better machining properties than the Cr-Mo steel. This is important since the vessel



Most of the 300 high-pressure valves installed are for low temperature operation, have ¼ in. bore and have non-rotating spindles with hardened tips. Rubber 'O' rings are used for gland sealing (Fig. 4)

head required much careful machining. The difficulties of manufacturing these vessels were increased by the tight dimensional tolerances necessary.

All material for these vessels was rigorously inspected. Tubes on arrival from suppliers were carefully inspected visually, radiographically, and ultrasonically to ensure freedom from flaws. Very high welding standards were called for and test welds were made as described above.

The fuel elements and radiation-damage steel specimens to be tested are loaded into a special inner assembly prior to insertion into the pressure vessel. Considerable attention was paid to the design of the vessel closure to ensure freedom from leaks. The primary seal is effected by a thin annular raised ridge on the underside of the inner-assembly top flange which is forced into a gold gasket mounted in a recess in the pressure-vessel head.

To remove the fuel elements and radiation-damage specimens the inner assembly will be lifted into a heavily shielded flask above the in-pile test section. Sufficient water is trapped in the inner assembly to ensure cooling of the irradiated fuel elements for some hours after unloading from the reactor.

High-pressure valves

Because of the need for minimizing the leakage rate from the loop, particular attention was devoted to select-

ing the best available high-pressure valves. More than 300 are installed and each represents a potential source of leakage. The large majority are designed for low-temperature use, are of $\frac{1}{4}$ in. bore, and have non-rotating spindles with hardened tips. Parts in contact with high-pressure loop water are largely made of austenitic stainless steel, the valve tips being made of a hardened martensitic stainless steel. Gland sealing is effected by means of rubber 'O' rings at the tops of the spindles (Figure 4). High-temperature valves of $\frac{1}{4}$ in. bore have the 'O' ring assemblies sufficiently remote from the high-temperature water to ensure that they are not overheated, a finned bonnet helping to dissipate the heat. Thrust bearings mounted in the valve bonnets reduce operating loads.

A small number of 0·96 in bore, high-pressure, high-temperature valves have been installed. These are generally similar to the $\frac{1}{4}$ in. valve except that they approximate to gate valves.

Certain critical valves can be operated from outside the shielded room by means of extended spindles containing universal joints. These pass through special gland assemblies in the floor of the shielded room, which are designed to prevent leakage along the spindles and also to preserve the required shielding.

Surge-tank level measurement

This is a particularly important parameter since it gives direct information on leakage rate, controls the makeup pump, and operates several high and low-level alarms and trips. The low-level trip is a protection against the surge-tank heaters becoming burnt out.

Two independent differential-pressure cells are employed for this purpose, connexions running from the top and bottom of the surge tank to either side of the diaphragm. Variations in level impose a varying differential pressure thus causing movement of the diaphragms. This operates an air valve and the downstream air pressure is thus a measure of surge-tank level. Pressure switches on this air line are set to open or close at the desired levels to control the make-up pump and the alarms and trips. One cell operates an indicating recorder and the other is connected to a large dial gauge. As pointed out in the article by Fontaine in the August 1958 issue, the calibration of such differential-pressure cells is temperature dependent, so two scales are fitted to the indicating instruments, one for expected operating conditions and the other for low-temperature conditions which apply during part of the start up.

If for any reason the surge tank became empty the heaters would no longer be submerged and would thus rapidly overheat, possibly sufficiently to melt the aluminium blocks, thus irreparably damaging the heaters. To safeguard against this contingency each heater block has a thermocouple inserted in it so that a dangerously low surge-tank level would be rapidly detected by a temperature rise, since the heat transfer coefficient to steam would be much less than to water. This temperature rise switches off the heater, operates the appropriate trips, and results in the loop being blown down into the quench tank.

Maintenance of clean conditions

For best use to be made of the chemical analysis of samples taken from the loop it was considered essential to remove all foreign matter from the internal loop surfaces. This was effected by thorough cleaning of components during manufacture and finally the complete loop. Mild-steel components were carefully degreased with trichlorethylene, pickled with inhibited 10% H_2SO_4, thoroughly rinsed with water, dried, and sealed to prevent ingress of moisture. Inhibitor was added to the acid so that it attacked oxide deposits in preference to the metal surface itself. In this way effective pickling was achieved with minimum removal of metal.

Machined stainless-steel components were degreased, passivated by immersion in 25% HNO_3, and finally washed with water, dried, and sealed. Stainless-steel tubes were found to have been contaminated by the tube drawing equipment and required pickling in a solution of 14% HCl and 16% HNO_3 in addition. Stainless-steel vessels were also pickled with inhibited 25% H_2SO_4.

During assembly of the loop, further contamination was caused, mainly due to oxide formation in welding. Consequently the complete loop was filled with inhibited 10% H_2SO_4, which was then circulated. Provision was made for safe disposal of hydrogen released during the reduction of the oxide deposits. The criterion for the extent of the pickling was taken to be the iron content of the acid. On completion of pickling, the loop was drained under a blanket of oxygen-free nitrogen and then refilled with deoxygenated water, which was circulated to remove pockets of trapped H_2SO_4 and finally drained. This process was repeated several times to remove all traces of acid.

Special care is taken to prevent ingress of oxygen into the loop to minimize corrosion. Water used for filling the loop is carefully deoxygenated and whenever the loop is emptied it is always pressurized with oxygen-free nitrogen.

COMMISSIONING TESTS

Commissioning tests began in November 1957 and a number of interesting points emerged. These are outlined below.

Leakage rate

Initially the leakage rate was much higher than permissible. The greatest sources of leakage were traced to the main circumferential bolted joints in the pumps and high-pressure valves. So far as could be seen the welding was entirely free from leakage. The leakage at the pumps was stopped by seal welding the offending joints. That from the valves was due to a combination of circumstances; it was reduced to acceptable proportions by ensuring that the valve assembly was carried out with the utmost care under close supervision and by taking care not to permit the rubber 'O' ring seals to be overheated. This latter measure was effected by repositioning the valves having symptoms of being overheated, and by replacing several low-temperature valves by high-temperature ones.

Difficulties were experienced with two valves used for emergency loop blowdown. These valves are normally cold but during emergency blowdown are subjected to considerable thermal stresses owing to a sudden increase in the temperature of the water flowing through them. This caused the removable valve seats to become loose after each blowdown, permitting severe leakage through the seat threads. The difficulty was overcome by modifying these valves by seal welding the seats in position. Misgivings were felt regarding erosion of these stellited valve seats by high-velocity water/steam mixtures during blow-

down. However in practice, after at least six blowdowns, no signs of valve-seat erosion have been observed.

Loop emergency blowdown system

This is an important safety measure and was tested several times by manual adjustment of the various parameters initiating its operation. Owing to the lack of time the quench-tank fittings had to be designed without any testing. It was therefore necessary to establish that adequate quenching of hot loop water would take place without water flashing to steam, so that excessive pressure would not be put on the drainage system and catch tank.

On one occasion a spurious loop blowdown occurred, initiated by a fault in the temperature gauge connected to the thermocouple in one of the surge-tank heaters. This fault gave a high-temperature indication, thus automatically initiating the blowdown, which was entirely satisfactory.

Instrumentation

Considerable trouble was experienced with pressure switches used for surge-tank heaters and make-up control, and in the safety circuitry. Contacts failed to operate as required and settings appeared to be different on starting up after lengthy shut-down periods. All such pressure switches were subsequently completely overhauled by UKAEA staff and minor modifications made which have greatly improved the reliability.

The flow-measuring equipment in parts of the loop consists of orifice plates connected to air-operated differential-pressure cells, the output pressure from which operates indicating recorders. Calibration was carried out by the manufacturers, and in at least one of these units considerable errors were found in calibration.

Initially a bubbler-type gauge was installed to measure the depth of liquid in the shielded catch tank and proved to be quite unsatisfactory. Inconsistent readings were indicated and the calibration was completely changed after the application of air pressure to empty the catch tank. All efforts to overcome these defects were unavailing, and it was finally decided to replace the gauge by a capacitance-change-probe type of instrument, which performed satisfactorily.

Pressure-vessel difficulties

The pressure vessels were designed by the UKAEA and proved somewhat difficult to manufacture to the very high standards required. With the need for high-temperature post-welding heat treatment, one of the major difficulties was achieving the required out-of-straightness tolerance of $\frac{1}{16}$ in. on an overall vessel length of some 11 feet. The tubes required for the highly stressed parts of the vessels were visually, radiographically, and ultrasonically inspected, and pressure tested to 4000 lb/in^2 before manufacture was started. Gas welding was used initially on the first vessel, but afterwards internal weld beads had to be removed from three welds. This operation proved more difficult than was expected and resulted in the occurrence of some tool marks in the bore of the vessel.

The contractor, in accordance with standard practice, used the double-wall radiographic technique, and on this basis all welds were regarded as acceptable by the inspection authority. However, on arrival at Harwell it was decided to re-radiograph the welds using a single-wall technique. This gave much more informative radiographs than the double-wall plates. One critical weld clearly lacked complete root fusion over a short length. Furthermore the effects of diametral weld shrinkage combined with weld-bead removal operations produced walls locally thinner than desirable. In view of these facts and the need for the highest standards of workmanship in pressure vessels of this type, it was thought prudent to reweld parts of this vessel.

It should be emphasized that although this precautionary measure was taken in view of the damage that might have resulted to the reactor if it had failed in service, it is very probable that the vessel would have performed satisfactorily. However, it was felt that no avoidable risks should be taken.

The contractors decided to use electric-arc welding when rebuilding this vessel since less heating of the vessel is caused than with gas, and the post-welding heat treatment is confined to a single low-temperature stress-relieving operation.

These points were important because of the need for straightness. The repaired vessel was given proof tests in accordance with BS 1500 in addition to pressure and hyrogen leak tests.

After the initial commissioning tests, inspection of the cooler showed that some corrosion of the high-pressure pipe coil had occurred. The water in the cooler tank was taken from the reactor cooling system and had been subjected to hydrogen-starvation and base-exchange treatments. It was considered that early action was necessary to prolong the working life of the cooler. The remedial action proposed consisted of treating the cooler as a low-pressure boiler. Cooler-tank water is now supplied from a separate storage tank where it is deoxygenated with N_2 and is then treated with Na_3PO_4 to give a pH of 11.

Start-up procedure

Care and attention must be exercised when starting up a loop of this type. From experience obtained on this and other loops a set start-up procedure has been developed, the principal features of which are described briefly below.

a. Cooling-water flow is provided to the pumps, cooler condenser, purification/sampling heat exchanger and vacuum-pump condenser.

b. To avoid possible damage it is essential that the loop water is degassed before the main loop pumps are started. This is done by pressurizing the loop by means of the makeup pump and opening each vent valve in turn.

c. At this stage the loop is completely filled with degassed water. Pressure is generated by switching on the surge-tank heaters, thus heating the water in the surge tank until a steam-filled space can be maintained above the water level. Water must be carefully bled from the loop during this process.

d. The operative main loop pump is started and the main-loop flow is adjusted to the required value. The main-loop heater sections are then switched on in turn to give the required temperature. To avoid undue thermal shock the loop temperature is increased to the normal operating value over a period of 1–2 hours.

e. In order to maintain the correct water conditions a small proportion of the flow is passed through the purification/sampling ion exchangers, care being taken not to exceed a temperature of 60°C at the ion-exchanger inlet to avoid damaging the resins.

ATOMIC POWER PROPOSALS IN AMERICA

1. Three stage plan by Westinghouse

AS PART of its normal nuclear activities, Westinghouse Electric Corporation is continuously evaluating all types of reactor, and three power plant projects have been put to US public utility companies as logical further steps in their plans to utilize nuclear energy. In two of these projects, the company are prepared to guarantee plant output, overall plant costs and fuel life. (See *Worldview* last month).

Combination Plant

Using both nuclear and fossil fuels, the combination plant is claimed to meet the present need of utility companies for an economical way of investing in the nuclear power future. Designed to supply a standard modern turbine of 225 MW, the boiling water reactor produces saturated steam which, after separation from the water, is passed direct to a fossil-fired superheater to provide steam conditions suitable for the turbine.

The reactor is fuelled with approximately 26½ tons of 2½%-enriched uranium dioxide pellets. The superheater can be fired with oil, gas or coal, the choice depending on individual user location and economics.

Construction of this type of combination plant could, say Westinghouse, be started immediately and the station could be in operation four years from the date of contract.

Feasibility studies on this concept have shown that all major technical problems are soluble. It has been found, for example, that a 2000 lb/in.² open-cycle reactor would actually be easier to control than one operating at 1000 lb/in².

The immediate construction of such a large plant is recommended on economic grounds. Based on a 90% load factor, fossil fuel costing 30 cents per million Btu, 0·5 mills per kWh for indirect costs, 12½% annual charges, and a plutonium credit of $12 per gram, the combination plant will produce electric power for 7·3 mills per kWh. This cost breaks down as 3·4 mills for capital investment; 2·7 mills for fuel; 0·5 mills for indirect costs and 0·7 mills for operation and maintenance.

Integral Boiling and Superheating

In this reactor high power density is achieved by both boiling and superheating within the core. No separate unit for superheating is required.

In operation, circulating water enters the centre region boiling tubes and is rapidly heated as it passes through the fuel region. This heated mixture of water and steam moves on up to one of four steam drums located above the reactor. The separated water is returned to the bottom of the boiling tubes in the centre region of the reactor; while the separated steam flows into the upper end of the superheating tubes located in the perimeter area of the core.

Within the carbon steel containment vessel, and completely blanketing the graphite moderator in all its vital areas, is helium at a pressure of 100 lb/in². This helium will control the heat transfer from the moderator to

COMBINATION PLANT

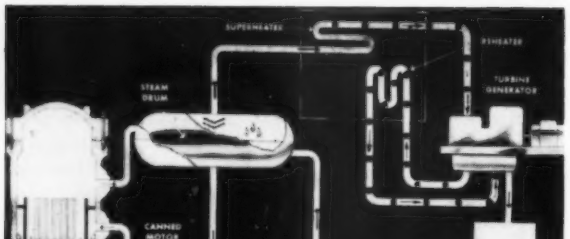
Net power rating	215 MWe
Reactor contribution	60%
Superheater contribution	40%
Steam conditions	2100 lb/in.² abs. dry and saturated
Fuel assembly form	Rod bundles
Material	UO_2 pellets
Cladding	Zr-2 or stainless steel
Reactor vessel, material	Stainless steel clad carbon steel
Design pressure	2500 lb/in.² abs.
Inside diameter	9 ft 3 in.
Shell thickness	8 in. plus ¼ in. cladding
Overall length	34 ft (approx.)
Steam separators	2 off
Design pressure	2500 lb/in.² abs.
Inside diameter	6 ft 6 in.
Overall length	21 ft
Recirculating pumps	4 off
Design pressure	2500 lb/in.² abs.
Flow per pump	12,500 gal/min
Superheater and reheat unit	Pressurized furnace type
Overall dimensions	146 ft × 76 ft × 65 ft
Turbine generator	Triple flow tandem compound
Operating pressure	1800 lb/in.² g
Operating temperature	1000°F/1000°F

INTEGRAL PLANT

Net power rating	20 MWe
Steam throttle conditions	865 lb/in.² at 900°F
Fuel assembly form	Rod bundles
Material	UO_2 pellets
Total pressure tubes in core	80 (approx.)
Design conditions in superheat region	1100 lb/in.² at 1000°F
Design conditions in boiling region	1200 lb/in.² at 650°F
Superheat tubes	24 (approx.)
Boiling tubes	56 (approx.)
Reactor tank design conditions	100 lb/in.² at 650°F
Material	Carbon steel
Outside diameter	12 ft 6 in.
Wall thickness	½ in.
Overall length	23 ft
Graphite core, height	14 ft (approx.)
Diameter	11 ft (approx.)
Steam drums design conditions	1200 lb/in.² at 600°F
Outside diameter	4 ft
Length	11 ft
Circulating pumps	2 off
Flow per pump	2570 gal/min
Helium circulator capacity	14,300 lb/h
Inlet temperature	740°F

CLOSED CYCLE PLANT

Net power rating	330 MWe
Steam throttle conditions	650 lb/in.², dry and saturated
Primary heat transfer loops	5 off
Total flow	75 × 10⁶ lb/h
Normal operating pressure	2150 lb/in.² abs.
Reactor vessel material	Stainless steel clad carbon steel
Design conditions	2500 lb/in.² abs. at 650°F
Overall length	41 ft
Inside diameter	11 ft 10 in.
Shell thickness	10 in. plus ¼ in. cladding
Weight of vessel	300 US tons
Steam generators	5 off
Material	Tubes stainless steel Shell carbon steel
Overall length	45 ft
Outside diameter of shell	9 ft 6 in.
Weight	150 US tons
Main coolant pumps (5 off)	Vertical, single stage radial flow
Design capacity	40,500 gal/min
Core design pressure	2500 lb/in.²
Coolant flow	75 × 10⁶ lb/h
Turbine generator	Tandem compound quadruple flow



Within the lifetime of a combination plant it is estimated that costs will even out in some US areas on a mills per kilowatt generating basis

the pressure tubes and at the same time maintain the graphite temperature within safe operational limits. This control is necessary since about 10% of the reactor's heat output originates in the graphite itself.

The integral boiling and superheating reactor, although a long step into the future, is considered by Westinghouse as ultimately proving to be a very economical and efficient unit in the 200 MW range. A comprehensive research and development programme coupled with the construction of a 20 MW prototype plant must, however, be undertaken. Among the problems to be solved is that of control. Within a few inches inside the reactor, temperature differences of nearly 400° will be encountered; the flow of water and steam through the two sections must be balanced and capable of meeting the surge demands of the turbine; and fuel performance in the higher temperatures of the superheat section will have to be evaluated.

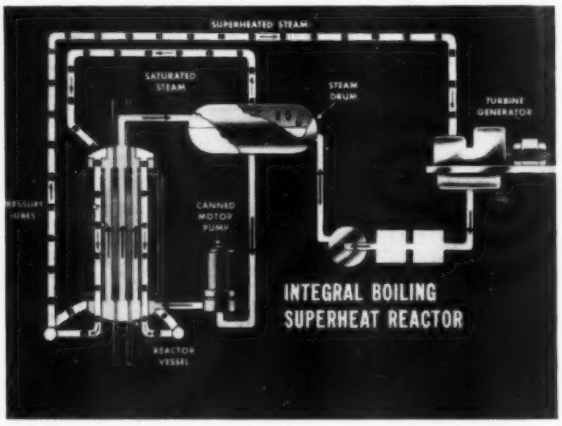
Closed Cycle Plant

Following feasibility studies of a closed-cycle plant at every rating from 5 MW to 400 MW, Westinghouse have found that power costs reduce sharply until 330 MW is reached, after which there is a marked levelling in the curve.

With a planned startup for early 1965, closed-cycle plants of about 300 MW rating are estimated to prove economical in the medium to high fuel cost areas of the United States. To obtain more uniform heating and better fuel economy, Westinghouse have developed a method of loading the core in three levels of enrichment. Looking down on the top of the reactor, three concentric zones form the fuel pattern. In the inner circle, the fuel enrichment will be about 2·1%; in the intermediate, 2·6%; and in the outer circle, 2·9%. Fuel life for this form of reactor is three full-power cycles. After each cycle the centre circle of fuel is removed, then the second and third layers are moved towards the centre and a new outer layer of 2·9% enrichment added.

The uniform heat rate that will result from this layout will allow the use of fewer control rods, less expensive fuel and kilowatts from a given fuel load.

Employing the same load factors and economics as for the combination plant, the all-nuclear closed-cycle type would be capable of producing electric power on a reasonably competitive mills/kWh basis. Estimated charges are 3·3 mills capital expenditure; 0·5 mills operational and maintenance charges; and 3·0 mills fuel costs, giving a total cost per kWh of 7·3 mills.



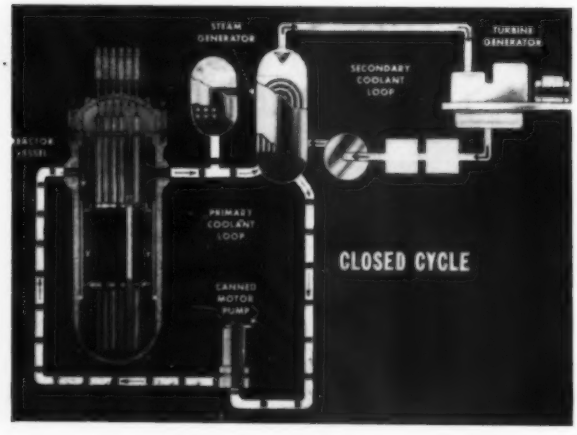
An advantage of the integral boiling superheat reactor, based on the use of pressure tubes, is that it is comparatively easy to make developmental modifications

Building costs

The 225 MW combination plant could be built essentially from today's technical know-how with no major research and development needed. This is reflected in the estimated R & D cost which is set at $M4½. The plant itself would cost around $M45.

The 20 MW prototype integral boiling and superheating reactor will require considerable research and development, the cost of which is put at $M11·3. Capital cost of the prototype itself is estimated at $M17.

Because of its proven design, the 330 MW closed-cycle plant will carry a relatively low research and development cost, estimated to be $M4·4, and the installation could be built for $M68, which in this high rating breaks down to a low capital investment per kilowatt-hour.



The closed cycle reactor is particularly efficient for ratings up to 330 MW. Beyond this power, the need for parallel sets of turbines to absorb the reactor output unduly increases capital costs

2. Task force surveys small reactors

IN MARCH this year a task force of personnel from AEC's Oak Ridge operations office began to study a possible programme for building small size nuclear power plants in the United States. With assistance from a technical advisory group from Oak Ridge National Laboratory and information submitted by a number of industrial firms and generating organizations, their report was published late in October. The report recommends construction of a 23·5 MWe PWR using slightly enriched UO_2 with a fossil fuel superheater coupled to a standard 'handbook' turbogenerator with a gross capability of 22 MWe.

Only three in the running

Initial screening of the various reactor types indicated that only the boiling water reactor (BWR), organic moderated reactor (OMR), and the pressurized water reactor (PWR) should receive detailed consideration. A survey of generating companies showed 22 MW to be the preferred size.

The total cost of conventional power, based on 60% capacity factor, is 10·9 mills/kWh and a comparable cost for the first generation plant is estimated to be 16·9 mills/kWh. Of this total, fuel and operation and maintenance charges are estimated at 8·6 mills/kWh for a nuclear plant as compared to a value of 7·8 mills/kWh for the conventional plant.

Because of the limited time available, special project reports on each of the three reactor types were requested, using appropriate AEC contractors, the main ones being:

1. BWR—General Nuclear Eng. Corp.
2. OMR—Atomics International
3. PWR—Alco Products Inc., including information from Westinghouse.

On the basis of this information, three designs were selected for evaluation on a standard comparative basis; their characteristics are shown in Table I. The BWR design is a direct cycle, natural circulation system in which the high pressure and low thermal time constant are projected to improve the stability markedly over other designs. However, the effect of this high pressure on the burnout heat flux may introduce a new limiting factor to offset the expected gains in stability. The OMR uses Santowax R as the coolant. Fuel elements are concentric tubular sections of 3·5 w/o Mo-U-0·5 w/o Si heat, canned in aluminium with extended fins.

In the PWR design it should be noted that the secondary pressure is somewhat lower than that actually obtained or projected for pressurized water plants. An improvement in secondary pressure is calculated to benefit further the net cycle efficiency and also the generating costs, depending on the associated capital costs required to achieve it.

Fossil superheating approved

The task force has recommended fossil fuel superheating. The PWR project reports, for the 25 MWe (gross) plant with and without superheat, show total costs of 14·9 and 16·0 respectively, or a difference of 1·1 mills/kWh.

Using the reactor characteristics of Table I and assuming values for fuel, operating and maintenance costs, etc., a detailed comparative estimate of costs was made; this is summarized in the table:

Cost component	BWR	OMR	PWR
Fixed charges	6·2	6·4	5·9
Total fuel	5·2	6·0	6·5
Operation and maintenance	2·0	2·5*	2·0
Total	13·4	14·9	14·4

** Includes 0·5 mills/kWh for organic makeup*

None of the three plants appeared to possess a clear-cut economic advantage over the others for a comparable state of technology at the present stage of their development. Although the BWR plant is estimated at the lowest total generating cost, the difference between its estimated total and that for the PWR is too small (about one mill) to be significant when the uncertainties of the estimates are taken into account. Furthermore, the advancement of technology which must be sucessfully achieved is most extreme in the case of the BWR plant. It is therefore apparent that the cost evaluations, although useful, do not in themselves provide a basis for discrimination between the various concepts.

Within this framework, the following general comments on each concept appeared appropriate:

1. The stated potential advantages of the direct cycle BWR, i.e., the attainment of lowest overall generating costs with high thermal efficiency, are also indicated by this estimate. The assurance of obtaining these advantages is somewhat obscured by the lack of sufficient experience with fuel element defects or failures, other than pin hole defects in the element. Direct cycle, fossil fuel superheat introduces both a potential corrosion problem with oxygenated steam because of the high thermal stresses in the superheater, and an operating concern because of a desire to avoid steam leaks in a direct cycle system.

2. During the period when nuclear superheat technology and associated costs are still speculative, the excellent steam conditions from the OMR associated with a low pressure primary loop and the possibility of minimum containment compared to other types makes it an extremely attractive concept. However, the lack of construction experience of a true prototype places it behind the other two concepts.

3. PWR technology has advanced to the point where construction cost reductions, through relaxation of unduly stringent component specifications and elaborate designs, may now be indicated by design, construction and maintenance experience.

The PWR concept offers excellent load following characteristics and a reliability and simplicity of total plant operation at present unmatched by any other competing reactor system. This advantage is obtained at the expense of a primary-secondary circuit design and attendent thermodynamic loss which may result in less favourable economics in the long term. Nevertheless, the construction of such a plant today, at the estimated capital and operating costs, would afford a major competitive target for second generation plants at a time when such a target is badly needed.

TABLE I *The three plants*

CHARACTERISTIC	BWR	OMR	PWR
Net MWe (plant)	23·5	23·5	23·5
Gross MWt (reactor)	47·0	57·2	57·1
Gross MWt (fossil fuel)	24·8	24·4	29·0
Gross MWt (total)	71·8	81·6	86·1
Net cycle efficiency	32·7	28·8	27·3
Fuel material	UO_2	U-Mo-Si	UO_2
Fuel form	pins	tubes	pins
Cladding	Zr-2	Al	s.s.
Average exposure, MWd/t	11,000	4500	11,400
Core charge, kg U	3796	8838	3335
Initial w/o U-235	1·70	1·75	4·00
Final w/o U-235	0·66	1·27	3·47
Reactor operating pressure, lb/in² g	1450	135	2200
Reactor operating temperature, °F	593	625	502
Steam pressure at turbine, lb/in² abs	1250	825	400
temperature, °F	1000	950	1000

A d.c. ionization chamber capable of operating at low flux levels is now commercially available and will be particularly useful in research reactors

Gamma compensated ionization chambers for reactor control

by A. L. GRAY, B.SC.
Chief Physicist, Plessey Nucleonics Ltd.

ADEQUATE CONTROL of a nuclear reactor requires measurement of the neutron flux level in the biological shield over a very wide range, which may be as much as 10 or 11 decades below the full power level (*1*). At the normal operating flux levels of most reactors simple d.c. ionization chambers may be used to give a unique measure of the thermal neutron flux. At low power levels and at shut-down, however, the usual solution adopted is to use pulse counters, rejecting the pulses due to gamma interactions from the high residual gamma fluxes in a pulse height discriminator. The lower cost and greater reliability of d.c. channels, however, makes their use desirable at as low a flux level as possible, in fact, until problems of statistics, noise and the measurement of the low current levels involved in practical ionization chambers make the use of pulse systems essential.

The extension of the range of d.c. channels to lower levels has been tackled, in this country, by the design of ionization chambers with the optimum neutron/gamma sensitivity and by the use of large thermal columns and lead shielding (*1*). The development of the well known RC1 chamber along these lines is described by Abson and Wade (*2*).

In other countries however, this approach does not seem to have been adopted to anything like the same extent. Instead attention has been directed to the development of gamma-compensated chambers in which the output of a second electrode system, sensitive only to gamma radiation, is connected in electrical opposition to that of the main neutron and gamma sensitive volume. These chambers have been used extensively abroad. The apparent neglect of the possibilities of detectors of this type in this country has been the cause of some criticism and, since recent developments have now made such chambers available, it is worthwhile at this stage to examine the problems involved in their design and use.

Detector siting

The detector positions chosen, and the consequent neutron and gamma flux distributions encountered, fall into three main classes, each characteristic of certain types of reactor.

The first of these is the radial hole in a biological shield, perpendicular to the core axis, which is characteristic of most large gas-cooled graphite-moderated reactors. In these holes anything but a nose-on position of the chamber with respect to the core is impracticable and the chamber is thus situated in neutron and gamma fluxes which decrease steeply along the axis.

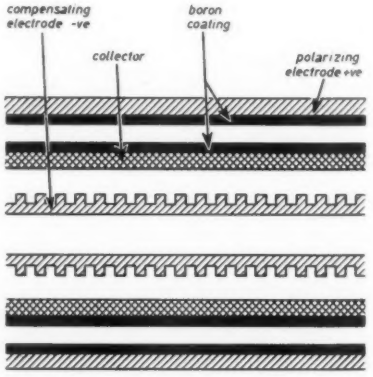
The second type of location is that commonly used in reactors with small highly enriched cores where the detectors are located in holes outside the pressure vessel parallel to the core axis and may be surrounded by shielding or moderating material. Here the predominant gradients lie across a diameter of the detector.

The third type is found principally in pool-type reactors such as Lido where the detectors are located close to the core in the moderator-coolant. Here there is usually considerable freedom of access but the core is usually very compact and very steep neutron flux gradients exist, accompanied by much smaller gamma gradients. These may lie in any direction relative to the chamber axis and it is usually impracticable to obtain either substantially axial or transverse gradients.

The design problem

The problems of design of gamma compensated ionization chambers are mainly concerned with minimizing the effect of the gamma distributions encountered in practice. If a location could be chosen in which the gamma flux was uniform and stable, the problem would be reduced to that of manufacturing two identical detectors, one of which was made neutron sensitive. In a non-uniform field it is however necessary that the two sensitive volumes be spatially coincident for the compensation to be independent of flux gradient. It is common practice to approach this as far as possible and then provide some form of adjustment to balance the effective sensitive volumes. This adjustment also serves to take up manufacturing tolerances.

Both parallel plate and concentric cylinder geometries are used for compensated chambers, the former in current French and Russian designs and the latter in the United States and in Great Britain. The parallel plate system usually consists of a series of circular parallel plates supported on pillars, each collector plate lying between a positive and negative electrode. The negative electrodes are uncoated, the collectors coated with boron on the side of the positive electrode and the positive electrodes coated on both sides. Thus there are alternating neutron-gamma and gamma sensitive sections along the axis of the detector, each of a length equal to twice the



Westinghouse electrically adjustable compensated chamber is a simple concentric cylinder design with deeply serrated negative electrode (Fig. 1)

electrode spacing. Cylindrical geometry involves simpler construction problems and is thus to be preferred where large numbers of detectors have to be made. The electrode system in this case consists of three coaxial cylinders, the neutron-gamma sensitive volume being that between the outer pair of electrodes.

The differences between the various designs using either of these geometries lie principally in the designers' attempts to reduce the effects of the spatial separation of the two volumes, the need to support and connect to the electrodes, and to accommodate manufacturing tolerances by the provision of compensation adjustment either during manufacture or after installation. The term 'variable or adjustable compensation' is usually reserved for those chambers where the compensation may be adjusted by the user, although all designs involve adjustment at some stage.

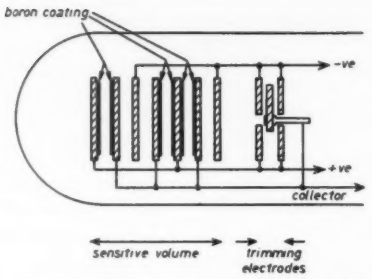
DIGEST

These new instruments extend the operating range of d.c. ionization chamber channels in high gamma fluxes. Their limitations lie mainly in the sensitivity of the compensation to flux gradients. Chambers with adjustable compensation are commonly used since they may be set up in situ but their performance may be unreliable over long periods. They are not recommended for power reactors where long term operation is required without adjustment: to obtain the stability necessary, chambers with a lower compensation ratio are preferable so that gradient shifts do not cause overcompensation.

Practical designs

The designs described here are not meant to represent an exhaustive list but rather to illustrate some interesting solutions to the problems.

The compensation ratio of a chamber is defined as the ratio of output current obtained in a gamma flux due to the neutron-gamma volume only, to that obtained with the neutron-gamma sensitive volume and the gamma sensitive volume connected in opposition. The compensation may also be expressed by the out of balance current, referred to as a percentage of the current from the neutron-gamma sensitive volume. Alternatively the term 'compensation factor' is sometimes used, the inverse of the compensation ratio. Thus a compensation ratio of 100 to 1, compensation to 1%, and a factor of 10^{-2} are all equivalent. The first two terms are the most common and are both used here as convenient.



The French CEA's type CCP IN 100 with its compact sensitive volume is well suited for location in a radial reactor hole (Fig. 2)

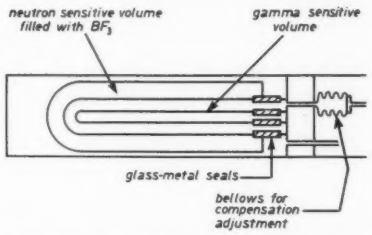
Westinghouse electrically compensated chamber

This chamber, described by McCreary and Bayard (*3*), is extensively used in the USA. It is essentially a simple concentric cylinder design, shown in section in Figure 1. The negative electrode is deeply serrated so that the collection characteristic of the gamma volume is more dependent on the negative polarizing potential than would be the case with a smooth electrode. Collection is some 90% complete at about 20 volts but the remaining 10% of the ions formed in the serrations are not collected until some few hundred volts are applied. This permits the effective volume of the gamma sensitive part of the chamber to be adjusted by varying the negative polarizing potential. The sensitive volume of this chamber is relatively long, about 14 inches, and this method of adjustment ensures a uniform variation of volume along its whole length so that the effects of changes in the gamma flux gradient are minimized.

Most applications of this chamber are in the second type of location described where the principal gradients lie across the chamber, in which direction it has its minimum dimensions. With the compensation adjusted to better than 1% when installed in the Oak Ridge graphite-moderated reactor, the effect of changing gamma gradients at the detector location was to change the compensation by 1·6% in six weeks. Frequent adjustment of the compensation is thus necessary to achieve the ratio of 100:1 claimed.

Compensated chambers of the French CEA

Two parallel plate compensated chambers were described by the Commissariat à l'Energie Atomique at the Geneva exhibition of 1958 (*4*). The larger of these, the type CCP 1N 100 has a very compact sensitive volume, about 3 in. diameter and 3 in. long, making it well suited for use in the first type of location described where the flux gradients lie along the chamber axis. The arrangement of the electrodes is shown in Figure 2. Each neutron-gamma volume is immediately adjacent to a compensating gamma volume so that the effect of an axial gradient is limited to the change over a distance equal to the electrode spacing. Even so this may well exceed the few percent to which compensation is desired and in this chamber provision is made for adjustment by a small subsidiary electrode system outside the main volume. A vane attached to the collector lead is movable between positive and negative polarizing electrodes, thus adding a small adjustable current to either half of the chamber as required. Since this is displaced axially from the main volume, it makes the adjustment of compensation highly sensitive to changes of gradient, but effective compensation ratios of the order of 300 : 1 are claimed.



The Russian KNK 54 chamber has two separately sealed volumes, one within the other (Fig. 3)

The smaller chamber type CCP 1N 50 has a similar electrode structure supported from a central column but without provision for adjustable compensation. The sensitive volume in this case is some 2 in. diameter by 2 in. long. The compensation ratio is stated to be 50:1.

Russian designs

A number of Russian designs were described at the 1958 Geneva conference by A. B. Dimitriev in a brief but interesting paper (*5*). The performance of these chambers is only sketchily described but a useful estimate can be made from the constructional data given. The paper covered three types, two parallel plate and one coaxial cylinder designs.

The parallel plate design type KNK 53 (also called KNT 53 in the paper) uses a three electrode system consisting of 164 disks, the disks of each electrode system being supported on two pillars. An unusually small spacing of

1·6 mm is used so that the sensitive volume is some 12 inches long. Neutron-gamma and gamma sensitive volumes alternate along the structure so that the mean effect of so many small collecting volumes is very close to true coincidence of the two sections. No details are given of the method of adjustment during manufacture beyond the statement that the quantitative relation between the two types of cell is adjusted. A compensation ratio of 1000:1 is claimed. A photograph of this chamber is given in the paper.

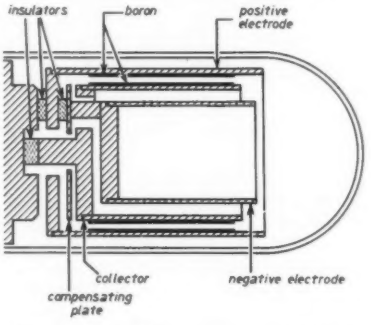
An interesting variant of this design is the KNK 52 in which the electrode system is deliberately made asymmetrical, the disposition of the cells along the axis being 12 gamma cells followed by eight neutron-gamma cells. This chamber is stated to be used for particularly close compensation; the out of balance current between the two volumes is reduced to the limit of measurement by adjustment of the chamber position in a gamma field having a maximum. Both this and the KNK 53 designs are most suitable for the second type of location owing to their long narrow sensitive volume.

The cylindrical electrode design, type KNK 54, shown in Figure 3, makes use of separately sealed volumes one within the other. The neutron-gamma volume is filled with BF_3 gas at high pressure and the gamma volume with a suitable heavy gas. Adjustment of compensation is effected initially by variation of the gamma section pressure and after installation a fine adjustment of pressure is provided mechanically by means of a small bellows. This chamber is also said to be used where closer compensation than that provided by the KNK 53 is required.

Harwell type RC6

The first compensated chamber to become commercially available in this country, this design is of the concentric cylinder type with the electrodes supported at one end only. A cross-section of a commercial version of this chamber is shown in Figure 4. The sensitive volume is defined at the free end by the virtual guard ring formed between the two polarizing electrodes at the end of the collector. At the other end of the collector, spaces between the electrode base plates contribute to the gamma sensitivity of the two sections. The physical separation of these two spaces and the absorption in the thick collector base plate between them would make the chamber very sensitive to axial gamma gradients, but the insertion of the compensating plate makes the space behind the collector base part of the gamma sensitive volume. Relative adjustment of the two volumes during manufacture is accomplished by fitting alternative sizes of compensating plate. Full details of the design and its performance are given in an AERE Report (*6*).

The geometry of the chamber makes it particularly suitable for use in radial holes with the nose of the chamber towards the core. A compensation ratio of about 30:1 is normally achieved



Harwell type RC 6 compensated chamber is available commercially as the Plessey Nucleonics type PNI 1025 shown here (Fig. 4)

which increases as the flux at the nose of the chamber increases above that at the tail.

Future development

The geometry which seems to offer the best hope of making a chamber insensitive to gamma flux gradient without excessive complication is the coaxial cylinder type with great attention paid to the reduction of end effects. The difficulties of manufacturing such a chamber with a high fixed compensation ratio, due to the tolerance attainable on cylindrical electrodes with simple manufacturing methods, render some form of final adjustment essential. Such an adjustment must have effect uniformly along the length of the sensitive volume.

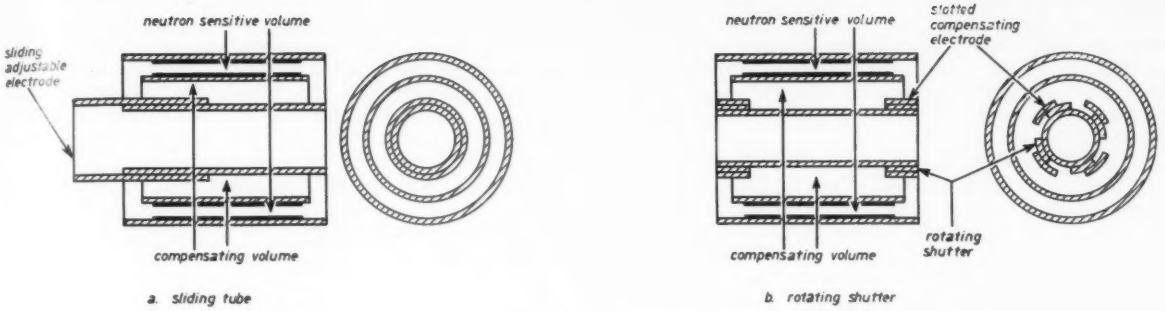
In the Westinghouse design this is accomplished by degrading the saturation characteristic of the inner volume and then making the adjustment electrically after installation. For reasons which are discussed later, the preferred approach in this country is to make the compensation fixed once manufacture is complete and as independent of operating conditions as possible. The problems involved in providing mechanical adjustment without affecting the sensitivity to gradients or the electrical characteristics are considerable. Two methods which have been studied at Plessey Nucleonics are illustrated in Figure 5 a and b. In the first of these the inner annular volume is adjusted by sliding a telescopic tube over the inner cylinder. As this is inserted it reduces the gamma volume. In any given field distribution this method gives extremely close compensation without great mechanical complication but the compensating volume is not distributed uniformly along the length. The second method makes use of an inner electrode which has four longitudinal slots which may be opened in varying amounts by a rotating shutter beneath them. A further cylinder inside the shutter defines the additional collecting volume to that added by the thickness of the shutter and the width of the slots exposed. Although this system adds increments of volume uniformly along the length, the collecting field is disturbed by the steps in the spacing and the compensation is excessively dependent on polarizing potential. It is also complex and expensive to manufacture.

A simpler system is now under development using an electrode system in which all three cylinders are slightly

TABLE I *Performance data for uncompensated and compensated ionization chambers*

TYPE	S_n amps/nv	$S\gamma$ amps/R/h	ϕeq nv=1R/h	COMPENSATION RATIO	REMARKS
UNCOMPENSATED CHAMBERS				—	using
AERE RC1	$1{\cdot}5 \times 10^{-14}$	$2{\cdot}0 \times 10^{-12}$	130		hydrogen
Plessey Nucleonics PNI 1026 (RC7)	$1{\cdot}7 \times 10^{-14}$	$2{\cdot}2 \times 10^{-12}$	130	—	filling pressure
Westinghouse WL 6937	$4{\cdot}4 \times 10^{-14}$	5×10^{-11}	1100	—	for optimum
GE 5467870G4	$2{\cdot}2 \times 10^{-14}$	$2{\cdot}2 \times 10^{-11}$	1000		ϕeq
GAMMA COMPENSATED CHAMBERS					
Plessey Nucleonics PNI 1025 (RC6)	$1{\cdot}2 \times 10^{-14}$	5×10^{-14}	4	30:1	fixed
Westinghouse WL 6377	4×10^{-14}	3×10^{-13}	7·5	100:1	adjustable
GE 5467870G2	2×10^{-14}	1×10^{-12}	50	20:1	fixed
CEA France CCP1N50	5×10^{-15}	5×10^{-14}	10	50:1	fixed
CCP1N 100	$1{\cdot}5 \times 10^{-14}$	3×10^{-14}*	2	300:1	adjustable
Russian KNK 53	$3{\cdot}6 \times 10^{-14}$*	$1{\cdot}2 \times 10^{-13}$*	3	1000:1	fixed

* *These values are calculated from available data and values of Sγ err on the low side as no account has been taken of stray volume.*



Experimental methods of mechanical compensation adjustment under study at Plesseys (Fig. 5)

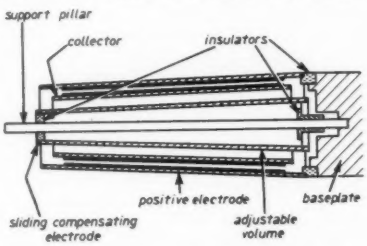
tapered* so that although a uniform spacing is maintained along their length, the volume of the gamma space may be simply adjusted by moving the inner electrode axially (Figure 6). This system may be applied equally well to chambers with short or long sensitive volumes although the problems of making the tapered electrodes increase with length. With careful design of the electrode supporting system very good collection characteristics can be obtained and the contribution to either sensitive volume by stray volumes made quite negligible.

Comparison of performance

The relative merits of various designs of compensated chambers are frequently compared in terms of compensation ratio but this may be very misleading. Since the purpose of the compensation is to discriminate against gamma background, the ultimate criterion of a design must be the relation between the useful gamma sensitivity and the neutron sensitivity. Useful gamma sensitivity in this sense means the lowest sensitivity which may be reliably assumed in normal use or between adjustments in the case of adjustable chamber. This is not necessarily the same as the published sensitivity and can usually only be determined by direct experience once the chamber is installed. A useful measure of the merit of a compensated chamber is the value of neutron flux ϕeq which yields the same output current as a gamma flux of 1 r/h.

The values of the sensitivities and ϕeq are shown in Table 1 for some of the chambers described together with the corresponding values for some uncompensated chambers. From the figures for uncompensated chambers it can be seen that the optimization of design in the RC1 described by Abson and Wade has in fact resulted in nearly an order of magnitude improvement in ϕeq for both the RC1 and RC7 over the Westinghouse and General Electric designs. This enables the performances of the compensated chambers to be seen in better perspective.

The RC6 chamber is normally set up during manufacture for a compensation ratio of about 30 in a uniform gamma field, giving a value of ϕeq of 4 nv. This ensures that in any gradient likely to be met in a graphite thermal column or water moderator the chamber never becomes over-compensated and users are advised to base performance figures on a factor of 10 i.e. a ϕeq of 12 nv which will be improved on in normal use. On this basis therefore the chamber is closely comparable in performance with the Westinghouse WL 6377 but without the attendent drawback of the need for adjustment.



The conical electrode system also being studied is both simple and efficient (Fig. 6)

The French adjustable chamber CCP 1N 100 would seem to have a rather better performance than the Westinghouse chamber but this is only achieved by a very fine adjustment in situ and may be expected to be more dependent on gradient. The performance of the Russian KNK 53 chamber is probably not as good as the table suggests as the value of ϕeq is based on estimated data, but it is certainly comparable with the best of the other chambers and should be very insensitive to changes in gamma flux gradient. It must however be costly to produce and adjust.

Suitable application

The choice of a compensated chamber must inevitably be very dependent on the type of operation for which the reactor is designed and the flux conditions available.

The location of the detector with relation to the reactor core will generally decide the shape of the sensitive volume which will make the best use of the available neutron flux. Consideration of the range to be covered and the relative neutron and gamma flux levels will then decide the extent to which compensation is necessary. As has already been mentioned, the greater simplicity of d.c. measuring systems has led to a tendency to specify compensated chambers wherever possible in place of pulse counters. The lower limit of neutron flux at which any d.c. ionization chamber may be used satisfactorily is primarily determined by considerations of statistics, noise and response time in the channels involved (usually period channels). The determination of this limit has been adequately described (*7, 8*) for uncompensated chambers and is identical for compensated types. Once this lower limit is known and the corresponding output current level fixed, the contribution to this current by the maximum gamma level expected at this neutron flux level can also be found, and the need for gamma compensation determined. Frequently the gamma levels are not known with any certainty and in such cases the use of a compensated chamber is often in the nature of an insurance policy.

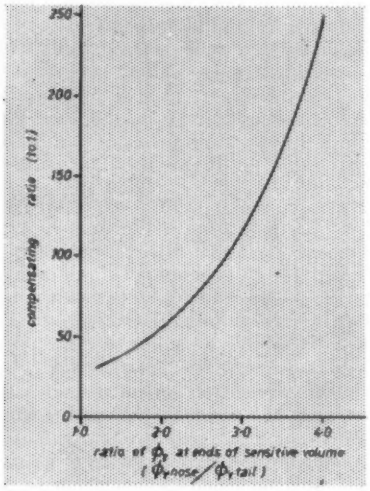
Adjustable chambers in research reactors

Where an adjustable chamber is to be used careful consideration must be given to the manner in which this adjustment is to be made. There is no difference in principle between adjustments made mechanically or those made by varying polarizing potentials, but where anything but the simplest shield plug assembly behind the chamber is used, the mechanical type is usually impracticable. As has been mentioned, the advantages claimed for the adjustable chamber are that it may be adjusted in situ for the flux gradients actually met. However, this cannot be

* *Patent applied for.*

done except when the reactor is shut down and only the residual gamma flux from fission products and induced activities is present. Where the fuel charge is a fresh one the level of this will probably be far too low to be measured so that the adjustment cannot be made until the reactor has been run for a time. Since between successive shut-down periods there is likely to be a change in the distribution of fission product activity in the core, it is likely that the compensation cannot be relied on after shutting down until a readjustment is made. Thus in the event of a short shut-down period, such as an accidental trip, where it may be desirable to get the reactor critical again as soon as possible, the lower end of the d.c. period range may be unreliable due to the uncertain compensation factor.

This could be very inconvenient if gradient shifts had made the chamber



Variation of compensation ratio with gamma flux gradient in the PNI 1025 (Fig. 7)

over-compensated so that at shut-down it produced a small negative current, driving the electrometer valve of the associated period meter into a region of very high input impedance. The long time constant of the input stage under these conditions would lead to severe overshoot difficulties once the power level was increased again. In a reactor where large sources have been used to bring the shut-down neutron flux to a level where d.c. channels are relied on for period protection the initial adjustment in the presence of this flux would be difficult and any over-compensation would render the period safety circuits inoperative and give widely differing readings on different measuring channels. The principle application of adjustable chambers is therefore likely to lie in research reactors where frequent shut-down periods permit a careful check to be kept on the compensation.

Similar considerations apply to the Russian KNK 52 chamber in which the compensation is adjusted by moving it in a field having a maximum. The paper refers to the need to do this each time the reactor is started up so that presumably the chamber is only used during start up, and adjusted in position to produce the minimum gamma current immediately before.

Large power reactors are expected to run for very long periods between shut-downs and during these periods to have many fuel rearrangements so that no stable or predictable pattern of gamma flux gradient can be expected in the chamber positions. It is for reasons of this nature that the approach in this country has been to produce chambers in which the compensation is adjusted mechanically to a reasonable value which is then fixed. In the PNI 1025 the ratio is between 20 and 30 to 1 for a uniform field, and in the normal nose-on position this improves as the gradient from nose to tail increases but does not approach the overcompensated conditions for any gradient likely to be met in practice (Figure 7). For the purpose of range calculations the compensation ratio should then be taken as 10:1 and this ensures that the gamma sensitivity will remain below the value used for calculations indefinitely and the chamber will not become overcompensated.

Limiting factors

Whichever type of compensated chamber is used more attention must be paid to the stability of the polarizing supplies than with two-electrode chambers. Even in the most carefully designed electrode systems collection in the saturation region may vary by a fraction of a percent per hundred volts and the collection characteristics of the gamma volumes are usually inferior to those of the neutron sensitive volume. Thus relative variations of the polarizing potentials can cause quite substantial shifts of the compensation. In the PNI 1025 (RC6) design the compensation remains substantially unaffected provided that the two potentials are equal, but can vary considerably if either changes alone due to competition between the two collecting fields at the ends of the electrodes (Table 2). Thus if battery supplies are used care must be taken that the two potential decrease together as the batteries age.

An additional limitation to the lower end of the range covered by d.c. channels is the residual activity of the ionization chambers themselves. Even though in most designs care is taken to reduce this by using pure materials with short half-lives, it may still provide a contribution as large as the gamma flux for short periods after shut down. In order to reduce this effect the ion chamber is often

TABLE II *Effect of polarizing potential on compensation ration in PNI 1025*

NEUTRON VOLUME	COMPENSATING VOLUME V_γ volts				
V_n volts	−500	−400	−300	−200	−100
500	**36**	26	20	15	11
400	54	**35**	23	17	12
300	166	59	**35**	20	14
200	−63	−166	100	**35**	18
100	−20	−27	−38	−330	**36**

The compensation ratio remains constant provided that both potentials are the same, but relative changes of potential cause an increase or decrease in compensation ratio.

retracted to a position of lower neutron flux at full power so that the activities built up will be correspondingly lower but this is not always convenient or practicable. Most compensated designs also provide some degree of compensation of the residual activity currents since the largest part of the effect is produced by the activity of the electrodes. The compensation will not usually be as good as that against external gamma fields nor will it vary in the same way with any compensation adjustment provided, but it may be sufficient to make retraction unnecessary. Since the effect is principally due to beta emission from the surfaces bounding the sensitive volumes, the compensation is likely to be best for the more symmetrical parallel plate designs. The only information available for the chambers described is that for the PNI 1025 (RC6) in which the compensation reduces the residual activity current by a factor of about 10.

Acknowledgements :

The author wishes to acknowledge with gratitude many helpful discussions with W. Abson and R. P. Henderson of Counters Group, Electronics Division, AERE, Harwell.

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Reactors

A thermocouple for reactor control

by J. L. AYRE, Ph.D., B.Sc.(Tech.), *Simon Carves Ltd.*

THE ACCURATE and rapid measurement of outlet gas temperature in the Hunterston reactors is essential for control at power, as this will provide the signal for the fine-control-rod mechanisms. Radial flux instabilities across the core may make manual fine control impracticable, and the core is divided into a number of radial zones each having independent automatic control. The outlet gas temperature is measured in approximately four hundred channels in a core of three thousand channels. Once installed the thermocouple assemblies must operate for the full life of the reactor.

It was proposed to use chromel-alumel thermocouples sheathed in stainless steel and situated in the top reflector course of the graphite core. In order to accommodate fuel-element withdrawal and access by servicing or charging gear the thermocouple assembly must be installed outside the main gas-stream flow. It was necessary to avoid direct thermal radiation from the topmost fuel element and to keep to a minimum the thermal radiation from the surrounding graphite reflector. In direct conflict with these requirements was the need for rapid response of the thermocouple to temperature transients in the fuel channel, and the additional requirement of installation of the thermocouple assembly after the core had been laid but immediately prior to the laying of the charge (or guide) pans. A design to meet these conditions could be achieved by housing the thermocouple in a concentric radiation shield which in turn could be housed in a recess on the side of the channel. The important problem was, of course, to ensure that gas would diverge from the main stream into the pocket, enter the concentric radiation shield, and flow over the thermocouple with the minimum loss of gas velocity. The flow pattern in such a system would be very complex for theoretical solution and it was proposed to base the design on investigations using dimensionally-similar models.

Water model technique

The reactor channel was represented in a water model by a rectangular perspex duct, the width being the same as the channel bore and the depth approximately half the channel bore. In the side of the duct there was a step, into which various arrangements could be inserted to simulate the pocket and assembly. Flow visualization was obtained by sized polystyrene of specific gravity 1·00–1·02. Illumination was provided by two mercury-vapour discharge lamps which were set on each side of the duct. By careful screening and contrasting, the polystyrene particles show up as bright traces of light, making the flow pattern visible.

Under dimensionally similar conditions a mean mainstream velocity of the carbon dioxide coolant gas of 30 ft/sec at 150 lb/in.^{2} and 750°F in a 5·25 in. i.d. channel, is represented by a velocity of approximately 10 ft/sec in the water model at atmospheric conditions, whereas in an air rig at the same Reynolds number the velocity would be about 120 ft/sec.

Tentative design

It was immediately apparent from the initial water-model experiments that the angle of divergency into the pocket and the length of the pocket were very critical. At angles of less than 10° to the axis of the duct the flow entered the pocket with no discernible separation from the wall. Between 18° and 20° the flow still entered, but did not follow the wall exactly. Above 20° the flow detached from the wall, and flow in the pocket was at a very low order and *counter* to the mainstream flow. When a cylinder representing the radiation shield was placed into such a pocket even this counter flow was inhibited, and the flow stagnated. From the initial survey it was concluded that an angle of 15° to the channel axis would

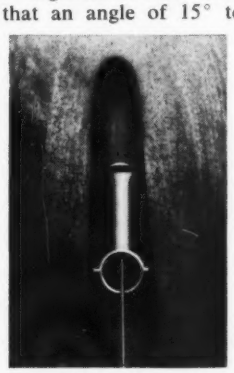


Fig 1 Full-size test design in wooden channel for air-rig tests

ensure entry of the stream into the pocket and that a 20° angle would be suitable to return the flow to the channel. The polystyrene particles appear as interrupted traces owing to the stroboscopic effect of the mercury-vapour lamps and provide an easy method of measuring approximately the local velocities, and with the angles mentioned above it appeared that the local velocities were 70% to 90% of the mean mainstream velocity. This was obtained from a metering orifice in the water-model circuit and verified within 2% by a total-head tube with a wall static tapping immediately upstream of the pocket.

Further work suggested the design of the radiation shield and a model of the complete assembly was produced. A lip on the radiation shield obscures the direct thermal radiation from the topmost fuel element to the thermocouple junction. Measurement of the polystyrene trace within the radiation shield was extremely difficult but appeared to be about 70–80% of the mean mainstream

velocity. The limit of usefulness of the polystyrene tracer was effectively reached after close study of a cine record showed an apparently satisfactory flow pattern. The tube representing the thermocouple was then used as a total-head tube and a small static tapping was placed in the side of the radiation shield. The ratio of the velocity in the radiation shield to the mainstream velocity was obtained from the square root of the ratio of the two differential heads of the two pitot arrangements. At the design Reynolds number this value was 78%. At 80% of the design Reynolds number the value was 75%.

Air-rig model

The design deduced from the water model was then copied for tests on an actual-size wooden channel and is shown in Figure 1. Again the thermocouple tube was represented by a total-head tube with a wall static tapping in the radiation shield. The wooden model was blown with air with the same upstream condition as used in the water model, i.e., with fairly low free-stream turbulence. It was only possible to obtain 80% of the design Reynolds number and at this value the ratio of the velocity at the thermocouple junction to the mean mainstream velocity (calculated from the metering orifice) was 74%. Thus, although the water-model duct was not a strictly true representation of a reactor channel the close tie-up with the air-rig tests shows that the approximation was justified and that a value of approximately 78% would be obtained at design conditions. This would produce a satisfactory rate of response in the thermocouple junction.

A GEC fuel element, i.e., having straight fins and helical 'swirlers', was placed 13 in. upstream of the assembly, corresponding to the position of the topmost fuel element when the channel is fully loaded. At 80% of the design Reynolds number the ratio of the two velocities was then slightly in excess of 100%. Further investigations showed that there was a long and stable wake behind the fuel element and that owing to the fuel-element design the gas was still moving predominantly in a helical motion at the entry to the thermocouple pocket. This fortuitously favourable condition would thus decrease the response time still further on a design which was satisfactory without the helical motion.

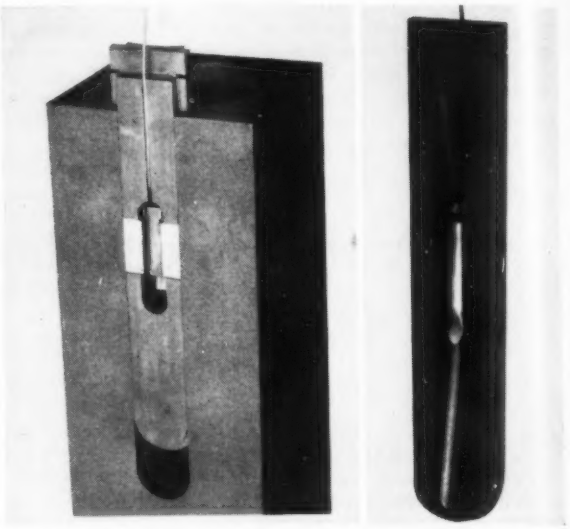


Fig 2 Two views of prototype assembly, show arrangement of thermocouple in pocket and method of keying insert into reflector block

Prototype assembly

The thermocouple pocket developed as a result of these studies is made as a keyed insert which slides into the reflector block after the core reflector has been laid. On this insert is carried the stainless steel radiation shield in which is housed the sheathed chromel-alumel thermocouple (Figure 2). The cross-secton of the radiation shield has been modified by manufacturing considerations, but the dimensions of the pocket and shield, and the relative positions of the lip on the radiation shield and the thermocouple junction, are as in the original water-model tests.

The prototype has been tested in a heated and pressurized carbon dioxide gas loop for accuracy and rate of response to transients in the gas temperature, and the design is in production for the Hunterston reactors.

Acknowledgements

This development was carried out in the laboratories of the GEC Atomic Energy Division, Erith, as part of the combined programme of The General Electric Co. Ltd., and Simon-Carves Ltd.

Materials

Heat transfer properties of Santowax R

by C. GROVE-PALMER, B.Sc., A.M.I.E.E. *and*
H. PASS, B.Eng., G.I.Mech.E., *AERE, Harwell*

THERE HAS been considerable interest in organic liquids as reactor coolants (and moderators) because of their low vapour pressure and non-corrosive nature. Another advantage is the low induced activity. That they have been so little used is due to the tendency of most organic compounds to polymerize when subjected to high temperature and to irradiation; the change in physical properties on polymerization causes a reduction in heat transfer performance. The organic material most resistant to the combined effects of high temperature and irradiation that has been found so far is terphenyl, available commercially as an isomeric mixture known as Santowax R. Even this would have to be used with a substantial polymer content in a power reactor. It should be noted that the experiments reported here refer to the unpolymerized material.

The material used has the following composition:— ortho terphenyl 8%, meta terphenyl 52%, paraterphenyl 39%, diphenyl less than 1%, ash content less than ·01%. The revelant physical properties were measured by Bowring and Garton (*2*).

Description of equipment

Both heat transfer and burnout experiments were carried out in loops constructed of 1 in. nominal bore tubing embodying the following features: pump, control valve, cooler, test section, dump tank, sample point, pressure/

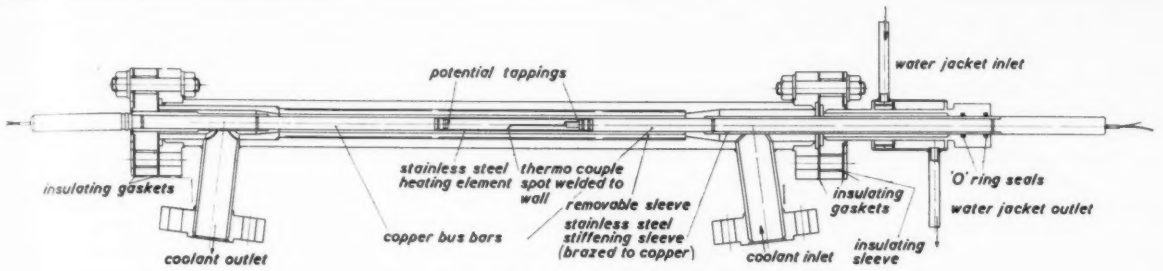


Fig. 1 Annular heat transfer test section

vacuum system, flanged joints, controlled trace heating, and instrumentation for flow measurement, temperature measurement, power measurement and power trips.

The pump is a gas bearing, centrifugal type, capable of delivering up to 20 gallons of fluid per minute against a head of 60 ft. The pump bowl is trace heated and the motor windings are cooled by a water jacket. The cooling section is a length of spirally finned tubing. The hot Santowax **R** passes through the central tube and is cooled by air flowing over the fins. The cooling rate is controlled by a gate valve in the air supply line.

The annular heat transfer test section is shown in Figure 1. The core of the annulus consists of a $\frac{1}{2}$ in. dia. thin-walled stainless steel tubular heating element brazed to copper bus bars which supply it with power from a low voltage high current transformer. The coolant flows in an 0·080 in. annular gap outside this core. The heating element is 5 in. long, giving a surface area of 7·84 in.^{2} (50 cm^2), the maximum heat flux obtainable being 400 watts/cm^2. The core, consisting of the stainless steel tube and bus bar assembly, is electrically insulated from the body of the test section. The lower bus bar is passed through an 'O' ring seal to atmosphere, to allow expansion of the core when the main heat is on. The whole test section is trace heated and losses are balanced by the trace heating at the start of each experimental run.

The sampling point is a small subsidiary loop in parallel with the main loop and isolated from it by two valves. To obtain a sample, the fluid is allowed to flow through the sampling loop, which is then isolated by closing the valves and freezing out. The section of pipe containing the sample is then removed. The pressure/vacuum system is a network of valves and pipes suitably connected to allow evacuating or pressurizing of the rig or dump tank or both. The vacuum facility is used to leak test the rig and to evacuate it before charging with Santowax. The pressurizing system is used to fill the rig by pressurizing the dump tank and also to provide an inert gas blanket pressure during normal running. All couplings in the gas system are of the High Pressure Yorkshire type. The flanged joints used throughout the rig were originally developed for liquid metal work. The seal is obtained by a raised nubbin on one of each pair of flanges, which applies a high local pressure to a soft iron gasket.

Trace heating of the rig is all obtained by electrical resistance heaters. The general pipework is wound with asbestos covered monel wire, the cooler, pump bowl and dump tank with $\frac{1}{8}$ in. dia. Pyrotenax metal sheathed heating cable, and the flanges and valves are fitted with Edwards type flat heaters. Control for the trace heating is obtained by supplying the heaters through either 'Variac' auto-transformers or through Simmerstats. The whole of the loop is lagged with a $1\frac{1}{2}$ in. layer of amosite asbestos.

Small valves are used to isolate the sampling loop and dump tank from the main circuit. They have a nickel cone on a stainless steel seat. It has been found that after several operations, a satisfactory seal can only be obtained by cooling to solidify the wax.

Flow measurement has been attempted in three ways with varying degrees of success. A conventional petroleum industry turbine flowmeter, as used in aircraft fuel systems, has been modified to withstand the high operating temperatures and has worked for over 1000 hours. A heated U-tube manometer using modified Klinger reflex gauges has been used connected to an orifice plate for flow measurement in the burnout rig and after initial difficulties with gas pockets in the supply lines, has proved to be reliable. One or two differential pressure cells have also been tried without success, but a current modification of a commercial unit has shown more promise of success in preliminary tests.

Temperatures throughout the rig are measured with chromel-alumel thermocouples. Those which give a general indication of temperature at discrete points throughout the rig are displayed on multi-point recorders. The temperatures which require more accurate measurement, i.e. those used in the heat transfer calculations, are obtained using calibrated thermocouples whose output is measured on a microvolt potentiometer. Power is measured using a Cambridge Multirange Wattmeter. The voltage coils are fed direct from potential tappings at each end of the stainless steel heating element and the current coils are fed through a 2000/5 amp current transformer. Power trips are built into the temperature recorders to ensure that the main heater supply ceases should any recorded temperature rise above 470°C and that the pump and main heater supplies both cease should any drop below 160°C. A flow switch is built into the pump cooling water line to isolate the pump and main heater if flow should fall below a fixed rate. An overriding power trip is built into the air blower supply to trip the pump and main heater if this should fail.

Experimental methods

The average bulk fluid temperature in the test section was obtained by taking the mean of the inlet and outlet temperatures. The element surface temperature was derived from the measured temperature inside the element. The coolant flow rate, blanket pressure and power dissipated in the test section were recorded to complete the quantities required to establish a heat transfer correlation. Heat losses from the test section were compensated by the trace heating which was adjusted to equalize the inlet and outlet temperatures with main heat off. This was re-adjusted as variations in running conditions were made.

The normal method of attack in the heat transfer experiments was to maintain the bulk fluid temperature, blanket pressure, and flow rate at constant pre-determined values, while the main heat flux was varied. Readings were taken at 15 minute intervals for any one setting and were recorded until four consecutive sets of values of inlet and outlet temperatures and element temperature fell within

acceptable tolerances. A constant watch was kept on flow rate and blanket pressure, and small adjustments were made as required. Average bulk fluid temperature was maintained at the correct value by adjusting cooling air flow each time the main power was changed.

The heat flux was first set at a low value of 50 watts/cm², and increased in 25 watt/cm² stages up to about 350 watts/cm² or until the burnout region was being approached. An indication that boiling heat transfer had been reached was given by a marked improvement in heat transfer coefficient. This was roughly calculated continuously as results were obtained.

As a preliminary to the full-scale burnout experiments, an investigation into the order of magnitude of burnout heat flux was made with a simple pool-boiling apparatus. This consisted essentially of a pool of Santowax in which a platinum wire heating element was immersed. By current and voltage measurements, both the power consumed and the resistance of the wire were determined. The power consumed was used to calculate heat flux and the resistance gave a measure of the temperature of the wire. The burnout heat flux was determined by raising the power consumed until burnout occurred. A constant observation of current and voltage was maintained. This experiment was repeated with the bulk fluid temperature at varying degrees of subcooling.

In the burnout experiments, the constant parameters during each run were: bulk fluid temperature, fluid flow rate and over-pressure; the variable was heat flux. The probable burnout heat flux was calculated from the Core and Sato correlation (*3*) and the initial power setting was approximately 50% of this figure. The power was then increased in steps of 10% of the predicted burnout heat flux until burnout occurred.

At each power setting, a check of inlet and outlet temperatures was made and the cooling air flow was adjusted to maintain the bulk fluid temperature at the required level. In the absence of a reliable burnout detector the test specimen was usually damaged when burnout occurred.

Results and discussion

A feature of organic liquid systems which may be a disadvantage is the deposition of polymerized material on heated surfaces. At the conclusion of each run in these experiments, the heat transfer test section was examined and it was found that even after the high temperature high heat flux runs, there was no fouling of the surface. On one occasion a thin black film was observed, but chemical analysis showed this to be iron oxide caused by the accidental inclusion of air in the rig due to ineffective purging of the loop prior to filling with Santowax. When physical burnout occurred there was usually some coke formed in the region of the burnout but it is considered that this was caused by the very high local temperature at burnout and was not the cause of the burnout. In one of the pool boiling tests a large deposit of coke was found on the wire suggesting that in conditions of low flow there may be fouling of the heated surfaces. However in the test loops the conditions of highest temperature and highest velocity occur at the same place and probably this prevents coke from being deposited. Table 1 presents the heat transfer and in Figure 2 they are compared with Dittus and Boelter ($Nu = 0.023\ Re^{0.8}\ Pr^{0.4}$).

TABLE 1 *Heat transfer results*

(a)	(b)	(c)	(d)
300	10	50	·52
300	15	50	·76
300	20	50	·96
300	25	50	1·13
350	10	50	·59
350	15	50	·80
350	20	50	1·02
350	25	50	1·24
400	10	100	·64
400	15	100	·84
400	20	100	1·15
400	25	100	1·35

TABLE 2 *Burn-out results*

(e)	(f)	(g)	(h)
300	30	15	380
300	30	20	350
350	30	10	250
300	100	1	100
		(Pool Boiling)	
250	0	0	150

(a) Bulk fluid temp °C (b) Coolant flow rate ft/sec (c) Blanket pressure lb/in.² (d) Average heat trans. coeff. watts/cm² °C (e) Bulk fluid temp °C (f) Blanket pressure lb/in.² (g) Flow rate ft/sec (h) Burnout heat flux-watt/cm²

The value of heat transfer coefficient was evaluated from a graph of heat flux v temperature difference, a typical example being given in Figure 3. An indication of the improvement in heat transfer obtained by boiling is seen from Figure 3 although at present sufficient work in the boiling region has not been carried out to make any firm recommendation. It can be seen that the equation, proposed by Dittus and Boelter (*4*), which is convenient in that all physical properties are evaluated at the bulk temperature, is a close fit to the experimental results. The maximum error is 3% and this is within the limits of experimental accuracy. Bley (*1*) in his report on polyphenyl heat transfer has recommended the following correlation: $Nu = 0.015\ Re^{0.85}$ and $Pr^{0.3}$. This was obtained by feed-

Fig. 2 Heat transfer results compared with Dittus and Boelter equation

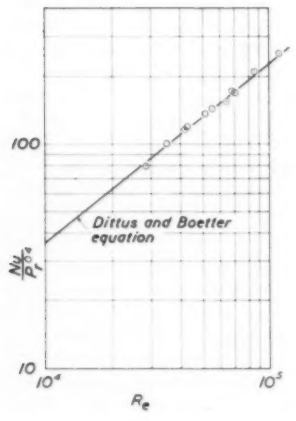
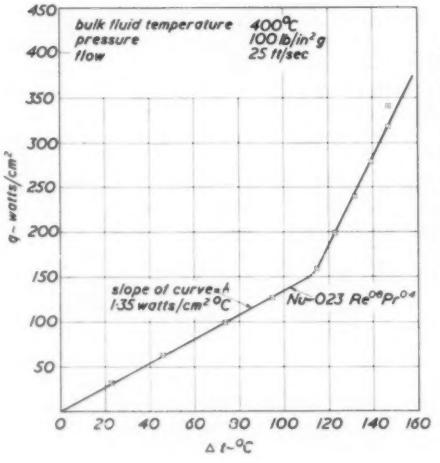
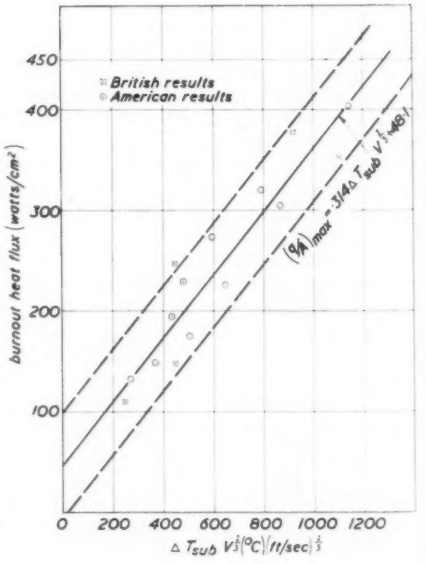


Fig. 3 (below) Heat flux v temperature difference. **Fig. 4** (right) Graphical representation of Core and Sato equation


bulk fluid temperature 400°C
pressure 100 lb/in²g
flow 25 ft/sec
slope of curve = A
1·35 watts/cm² °C
Nu=023 Re^0·8 Pr^0·4
q - watts/cm²
Δ t - °C
0 20 40 60 80 100 120 140 160
50 100 150 200 250 300 350 400 450



ing all the experimental results for several polyphenyls into an IBM 704 computer to determine the best values of the constant factor and the exponents of Reyolds number and Prandtl number. It was found that the results of the work reported in this paper could be correlated by the American equation, but not as closely as by the standard Dittus and Boelter equation. It is considered that in the absence of significant variation from this standard equation no attempt to formulate a new correlation is justified.

The burnout results are given in Table 2. An attempt at a general correlation of burnout data for liquids was made by Griffiths (*5*) for a single heating element in an annular flow passage. This relationship can be used in conjunction with the Griffiths curve to predict, within a fairly wide margin, the burnout heat flux, for a given set of rig conditions. The experimental points obtained in this investigation lie slightly above the upper limit predicted by Griffiths. This may be partly offset by the difference between the British and American definitions of burnout. The British concept of burnout is: ' that heat flux at which burnout occurs ', while the Americans use the highest heat flux obtainable with steady state conditions before burnout occurs. The latter can be as much as 10% less than the heat flux at the actual burnout point.

Use of this correlation necessarily involves much arithmetic and, to avoid this, several experimenters have devised simpler empirical correlations which can be used in very narrow fields. A convenient equation for use with Santowax R has been obtained by Core and Sato (*3*). This relates burnout heat flux, sub-cooling and coolant velocity. It is $(q/a)_{max} = 552 \triangle T_{sub} V^{2/3} + 152{,}000$ where $(q/a)_{max}$ = burnout heat flux, $\triangle T_{sub}$ = sub-cooling and V = velocity. The units used are British. The equivalent equation in the units of this paper is $(q/a)_{max} = 0{\cdot}314 \triangle T_{sub} V^{2/3} + 48{\cdot}1$ where $(q/a)_{max}$ is in watts/cm.^{2}, $\triangle T_{sub}$ is in °C and V is in ft/sec. This relationship is presented graphically in Figure 4 with the experimental points shown. This empirical correlation takes no account of L/D ratio and it is fortuitious that the apparatus of Core and Sato was similar in shape and size to that described here.

The overall effect on heat transfer coefficient of experimental error has been calculated from the known possible errors in measurement and it is not more than 10% in the worst possible case.

Conclusions

Unpolymerized Santowax R in the absence of radiation can be operated at bulk fluid temperature up to 400°C in contact with a heated surface at a temperature up to 520°C without any fouling of the heated surface, provided that adequate flow is maintained. The work has shown that the standard Dittus and Boelter equation $Nu = 0{\cdot}023\ Re^{0{\cdot}8}\ Pr^{0{\cdot}4}$ can be used to correlate heat transfer data for Santowax R. This equation is preferred to the new one proposed by Bley and has shown good agreement with the results reported even with the much higher heat fluxes which have been obtained in the present experiments. Burnout heat flux values slightly higher than the values suggested by the Griffith correlation have been obtained, and it is considered that the Core and Sato correlation can be used to predict burnout heat flux more closely. These indicate that a heat flux of 300 watts/cm^2 can be safely sustained when the bulk fluid temperature is 350°C with a fluid velocity of 20 ft/sec. and 100 lb/in.^{2} system pressure.

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5. Griffiths, P. ' The Correlation of Nucleate Boiling Burnout Data.' *Soc. Mech. Eng. Paper No. 57-HT-21, A.S.M.E.—A.I.Ch.E. Heat Transfer Conference*, University Park, Pa., August 1957.

Instrumentation

Packaged switching circuits

US National Bureau of Standards

A SERIES of transistorized computer packages for preliminary processing of data is being developed under the direction of Mr. J. A. Cunningham at the National Bureau of Standards. Each package is constructed on a 4 in. by 5 in. plug-in printed board, and most of them contain type 2N414 transistors; some use types 2N363 or 2N123. Units developed so far include:

The flip-flop This consists of two bistable flip-flop circuits and the necessary logical gating for converting each to one of several modes of operation. A normally open switch can be connected to the collector of either transistor to reset the flip-flop. In each package is also sufficient circuitry to construct one bit of a double-rank shift register or two bits of a serial shift register. The output of the package can drive 5 other flip-flops, 5 OR-inverter circuits, 8 gate resistors, or 5 gate capacitors.

The gating package This contains 8 logical gating circuits consisting of resistor-diode networks with capacitor inputs. They are mainly to supplement the gates in the flip-flop packages to complete the component requirements of shift registers, counters, or other systems. They can transfer information from a shift register or form feedback paths in various counting configurations. These gates can be driven by the output of a flip-flop, a ' one-shot ' pulse generator, an OR-inverter, or a power driver.

The ' one shot ' pulse generator A single pulse whose duration is variable from 20 to 10,000 μ sec can be delivered. Regardless of the duration of the pulse, the circuit is prepared to generate a new pulse 20 μ sec after the initiation of the first. The package consists of a flip-flop identical to the one in the flip-flop package, together with an integrator, a discriminator, and an amplifier. After the flip-flop is triggered, its output is integrated. When this integrated signal reaches a predetermined level, the discriminator is triggered. Its output is differentiated, amplified, and inverted, then differentiated again before being fed back to reset the flip-flop. The output, which can be either positive or negative, has the same driving capabilities as the flip-flop package.

The OR-inverter Each of these packages, which can also be used as an AND-inverter, contains four separate 4-input inverter circuits. For negative input pulses, the 4 input diodes function as an OR-gate; for positive inputs, the diodes serve as an AND-gate. The output of the gate is amplified and inverted. One of these packages can drive 6 other similar packages, 6 flip-flops, 8 gate resistors, or 6 gate capacitors.

Cross Section by GRACCHUS

ORGANIZERS of official openings usually follow the well-tried rule: have plenty of speeches, perhaps a small inspection or two, but don't let anyone actually *do* anything. Those who ignore this and prefer to risk some action are liable to play into the hands of the devil that waits on demonstrations.

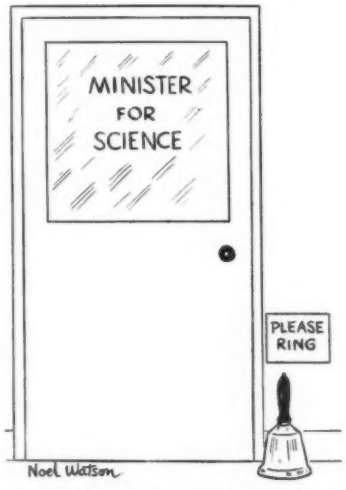
The invitation had merely stated that HRH The Duke of Edinburgh would 'open' Merlin, and until the ceremony was well on its way I assumed the first school of thought was being adhered to. But having looked over the reactor hall the Prince disappeared with his party into the control room for several minutes and word went round the guests that he was going to start it up. Then he emerged looking slightly cross, and it began to dawn on us that Merlin wasn't playing. It was with a definite air of anticlimax that the Prince stepped forward, pulled the string to unveil the dedication plate let into the reactor wall, and marched out. Feeling rather let down we all filed back to the marquee for tea and then out to the waiting cars for home.

The next day I heard that Prince Philip really had sent Merlin critical. Rather puzzled, I made a few enquiries. We had reckoned without the Royal persistence. Apparently, having been baulked in the control room ('Look, we've got to get this thing going') he stayed at Aldermaston Court and filled in time with a tour of the laboratories until the staff had corrected the fault. So Merlin was finally started up, in the presence of only a handful of spectators, and HRH departed in triumph.

The Prince is well known for his interest in science, though as he freely admitted in his speech, his actual knowledge is limited. 'What I do know has been mostly picked up from visits like this,' he said. He had a kind word for AEI's arrangement with various educational institutions, including the Universities of London, Reading and Southampton, for them to send students along to use the reactor as part of their courses. 'The advancement of research depends on specially trained people as well as on facilities, and this arrangement is a recognition that they have to go together.'

After hearing and reading a number of remarks lately about the waste of overlapping research and the necessity for tightening the (money) belts I was pleased to hear the Prince finish his speech by urging the importance of steady research on a broad front, and emphasizing that 'a rapid advance is only possible if the same problem is tackled by a number of people in different ways.'

FRESH from his election triumph, Lord Hailsham certainly brings confidence and enthusiasm to his new job as Minister for (not 'of') Science. But, one



may ask, is that all? It has to be, for Parliamentary Government is, as he reminded me, 'in the main, Government by amateurs advised by experts.' Curiously enough, this generally works, providing the Minister has a genuine interest in the subject and is not just treating his post as another Cabinet rung. Hailsham's interest in science—as befits the grandson of Quintin Hogg, the founder of the Polytechnic—is, I am sure, very genuine and he certainly cannot be labelled a career politician. One of the first fruits of his new appointment should be the publication of the Zuckerman Report on the techniques of management and control of Government-financed research and development. This inquiry was instigated by Lord Hailsham during the last Parliament and it was originally headed by Sir Claude Gibb. After Gibb's death in January 1958, the job was taken on by Sir Solly Zuckerman and I understand his report is just about ready. The recommendations should form an interesting footnote to the Select Committee's recent finding on the AEA's old Industrial Group.

A MECHANICAL engineer acquaintance the other day was complaining of his difficulty in understanding electronics. He is a pre-war graduate and so did not have to take this subject—which wasn't invented anyway when he was at the university. To be good at electronics you certainly have to have a sort of vocation for it, but any engineer ought to be able to get as far as reading a simple circuit. In thinking about it however I was struck by a unique feature of electronics—it is really about the only engineering subject in which 'do-it-yourself' is thoroughly practicable.

A mechanical engineer cannot easily in his bedroom build a diesel engine, or a centreless grinder. A civil engineer cannot, in his backyard, construct an arch dam or a bridge. But the electronics man can, at very little expense if he 'shops around', easily build a useful—and thoroughly real—piece of his own kind of engineering. Thus in his case theory and practice can be brought into very intimate contact with each other with incalculable benefit. In actual fact most electronics men do—or at one period in their lives, did—play around at home with radios, amplifiers, television and what have you. Electronics, in other words, is often their hobby as well as their job.

On Record

Companies entering the nuclear industry have received relatively little in return for their investment. . . . Unless there is some revision of national policy much of their technical effort in this field will have to be discontinued.

Sir George Dowty, Chairman, Dowty Group Ltd.

The failure of the Free Trade Area talks convinced us, more than anything else could have done, that our basic policy of first priority for Commonwealth investment is entirely right. —Pye Annual Report.

Her passion was almost nuclear in its intensity.

—from a story in 'Ace' paperbacks

Naval and mercantile projects move ahead

development facilities at Yarrow

ON THE occasion of the launching of HMS *Brighton* at Scotstoun on October 30, the builders, Yarrow & Co. Ltd., revealed their extensive activities in the field of nuclear marine propulsion. This work is based on a research department which the company, in collaboration with the Admiralty, set up in 1946 for the purpose of carrying out fundamental investigations into all aspects of naval engineering design. Known as the Yarrow-Admiralty Research Department, Y-ARD, it is staffed purely by company's personnel and is employed by the Government on a contract basis.

Just before the launching, Rear-Admiral G. A. M. Wilson, in charge of nuclear propulsion at the Admiralty, said that while it was very difficult to give estimates in the nuclear field, it was his guess that it would be ten years at least before there was a truly economic nuclear powered ship afloat. He went on to say that building should not be delayed on this score as he did not think it was possible to break even economically until operating experience was available to back up research.

Since 1955 Yarrow's works have been modernized and expanded, especially the experimental facilities and test shops, at a cost of £M1. Over the past two years Y-ARD have carried out comprehensive design studies under the direction of the Admiralty in the application of nuclear propulsion for a fast fleet replenishment ship. Other studies at Yarrow include nuclear propelled surface warships for the Royal Navy and the feasibility of providing economic nuclear power for a large commercial tanker. At the present time, engineers from the Royal Canadian Navy and the Canadian Department of Transport are working at Y-ARD on nuclear projects with particular emphasis on ice-breakers and mercantile vessels suitable for operation in Arctic waters.

Waiting for a decision

Close contact has been maintained with the Marine Nuclear Propulsion Committee, generally referred to as the Galbraith Committee, for which Y-ARD have carried out feasibility studies. This work is being carried out on a continuing basis with the individual companies submitting additional data to Yarrows as their designs are developed. Already the GEC have submitted three supplementary concepts which have been passed on to the Galbraith Committee and English Electric have been consulted on OMRs for marine purposes.

To further this work, Y-ARD have completed the design of the conventional propelling machinery and associated control equipment which could be utilized in conjunction with any of the reactor proposals so far submitted to them.

No decision has yet been announced on the type of reactor to be chosen for the first nuclear naval vessel, but Admiralty officials have expressed a preference for a purely British design. Despite the recent announcement by Mr. John Hay, Parliamentary Secretary, Ministry of Transport, that the AGR in sizes suitable for marine applications would not be economical, Y-ARD's directors are of the opinion that, with very limited modification, the Atomic Energy Authority's AGR would prove suitable for the Navy.

Facilities available

Parallel with their nuclear work, Yarrow have developed dual steam and gas turbine propulsion units and this type of installation could be readily adapted for use with reactors. By employing such an arrangement, the difficulty of having to run the reactor during maneouvring in port, when widely fluctuating loads are required, would be overcome.

Although the Ministry of Transport will be responsible for mercantile applications, Y-ARD will be engaged initially on this work. So that their works can be kept abreast of current requirements in the fabrication of components and assemblies, a wide range of subcontracting has been accepted for items to be installed in the power stations now under construction—these include the main coolant valves and ducting for Berkeley. To support these activities, 'clean' conditions for large items have been established with full inspection facilities, including 400 kV X-ray equipment for 100% radiographic examination.

Looking for clients

Yarrow & Co. Ltd. are not the only shipbuilders anxious to start building a nuclear-propelled vessel. Mitchells, in conjunction with their associates, Fairfields, have developed their proposals very considerably over the past eighteen months. During this time they have continuously worked up their original proposals for the Galbraith Committee so that today even hull design details have been completed.

As the Government has not yet indicated any practical programme in this field, Mitchells have looked overseas for possible clients and already several enquiries have been received from European shipowners. To put their proposals on a firm commercial footing, Mitchells are now prepared to offer hull and machinery, including reactor, on a fixed price basis and

The expanded facilities of Yarrow's yard now include a new test house (on the left) and Y-ARD's building (top right)

guarantee delivery within thirty months for units up to 20,000 s.h.p. in size. They expect that the initial vessels will be 50,000 dwt, will operate at a service speed of 16¼ knots and achieve 17½ knots on acceptance trials.

American adaptation

Members of another company, Hawker Siddeley Nuclear Power Co. Ltd., in collaboration with naval architects, have directed their feasibility studies to smaller commercial vessels that could be put into operation within five or six years. On October 7, Dr. E. C. B. Corlett, a naval architect, and E. P. Hawthorne of Hawker Siddeley, presented a paper, 'The prospects for a nuclear powered dry cargo liner with particular reference to the organic moderated reactor,' to the Joint Panel on Nuclear Marine Propulsion at the Institute of Naval Architects.

In this paper, proposals for a 25,000 ton, partially refrigerated, cargo vessel, based on the US Mariner Class, such as would be suitable for the UK-Australia or New Zealand route were put forward. A 64 MW OMR, utilizing stainless steel clad UO_2 with 1·6 to 1·8% initial enrichment, was recommended as the prime power source. In comparison with a similar-sized conventional vessel, it was estimated that annual operations would result in greater profits (£347,900 against £317,600 for the conventional ship) although profit per cent on capital (8·8% against 11·2%) capital cost/ton cargo (£60·7 against £53·5) and profit/ton cargo per annum (£5·3 against £6·0) were all lower.

Based on normal development probabilities for the OMR, the operating costs were estimated to be reduced subsequently in two stages. Initially, capital costs arising out of experience would come down and lower fuel costs would be obtained by improved canning materials. The second stage would also benefit from reduced capital costs, assessed at 20%, and fuel costs would be cut by as much as 40% by using plutonium fuel.

When ?

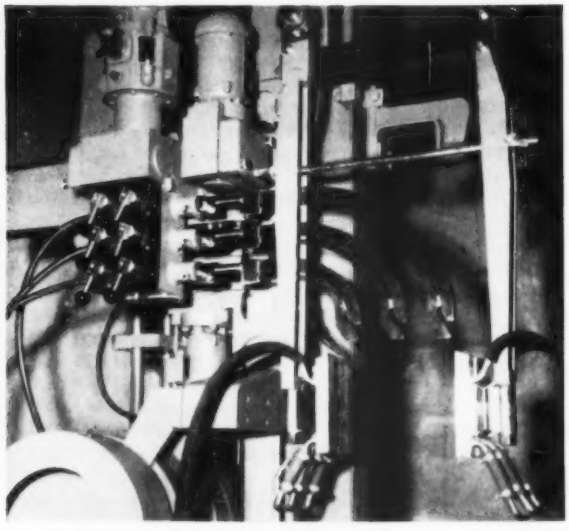
With detailed designs completed or nearing completion, fabrication and associated inspection facilities being established, British nuclear engineering and shipbuilding companies are now approaching the time when the keel of the first British nuclear-powered ship could be laid.

PROGRESS IN INDUSTRY

Heavy plate engineering

new Rockweld welding technique

ELIMINATION of plate edge preparation and ability to deal with thicknesses up to 8 in. are two of the advantages of the electro-slag technique of welding for which Rockweld's Vertomatic machine has recently been introduced. This process is fundamentally different from submerged arc automatic welding in that flame-cutting of the edges is adequate and even the heaviest thicknesses are joined in one single operation, reducing rod and energy consumption by as much as 35%.



The cooled shoes carry probes controlling automatic vertical travel and flux feeding. The electrodes are fed through the three guides at a constant speed to suit the specific job. An auxiliary control is fitted for automatic rotation when work is mounted on motorized rolls

With a welding current of 500 amps, 0·4 lb/min weld deposition can be made with this electro-slag process, as compared with 0·26 lb/min with the submerged arc technique or a maximum of 0·13 lb/min (at 400 amps) for manual electrode application. To provide uniformity of welds and standard of operation, all movements are motorized and carried out automatically.

The Vertomatic machine, designed and built by Rockweld Ltd., has made these vertical welds in tests:

1. *Longitudinal welds of two half cylinders of 2 in. plate with an internal diameter of 21¼ in. at a rate of 43 inches per hour.*

2. *T-welds of 2 in. plate to 2½ in. plate, at 31½ inches per hour.*

3. *Butt welds of 8 in. plates, at 27½ inches per hour.*

The machine consists essentially of a transportable frame on which is mounted the main vertical track. This carries a secondary horizontal track along which the wire racks, wire guides, cooled shoes and flux delivery unit are positioned. Welding current recorders, controls for up to three electrodes and motor switches are all centralized in one compact control unit.

For heavy thicknesses of plate, the electrodes are given a horizontal traversing motion during feeding into the joint.

While the adaptation of this welding process calls for the conversion from the more usual horizontal to vertical welding, which must be considered at the design stage and which may necessitate modifying the shop layout, the metallurgical properties of the finished joints are very good.

Tests on 2 in. boiler plate in the as welded state give a tensile strength of 34 tons/in². Under Charpy notched bar tests for transverse testing with the notch parallel to the weld and facing the weld surface, results, in ft/lb, are:

TEMP	LOCATION BACK	CENTRE	FRONT
At 20°C (room temperature)	42	46	50
0°C	28	50	32
−20°C	15	44	14
−40°C	6	20	10

New Product Survey

PLANT · EQUIPMENT · INSTRUMENTS · MATERIALS

PROCESSING ACCELERATORS

lower radiation costs

New developments in processing accelerators by High Voltage include three new types of intense radiation sources, and more efficient techniques of electron beam utilization which will cover the entire range of industrial power requirements from 10 to 1000 kilowatts.

The most important is the insulated core transformer accelerator which utilizes a segmented magnetic core permitting large voltage buildups in the secondary windings of each segment without the requirement for high voltage insulation between winding and core. Each core segment, with associated windings and rectifier, is a compact d.c. power supply capable of delivering 30 kilovolts and 40 milliamperes of current. Voltage addition is obtained by distributed series capacitance between core segments. The overall efficiency of power conversion is about 90 per cent. An electron accelerator utilizing this principle has been constructed and is now under test at HVEC's Burlington plant.

Another electromagnet voltage generator is the transmission line accelerator which is an inherently simple device for obtaining over 20 milliamperes average beam current in the power range of 10 to 75 kilowatts, depending on energy range. The prototype is under construction and power efficiency is expected to be over 80 per cent.

The third type, the multiple disk accelerator is being constructed to deliver 15 to 25 milliamperes at 1·5 MeV, 25 to 100 kilowatts power range.

Recent techniques of beam deflection or diffusion have permitted higher beam currents with less power absorption at the 'window.' A 30-inch line scanning beam has been successfully used with a 1·5 MeV Van de Graaff accelerator to provide uniform coverage of wide film.

Tick **No 208** on reply card

CARTRIDGE CONDENSER

greater efficiency, less space

An extension to their range of graphite heat exchange equipment has been made by Powell Duffryn. This addition is a condensing unit for handling corrosive vapours and consists of a graphite element or cartridge enclosed in a cylindrical steel jacket with carbon inlet and outlet heads.

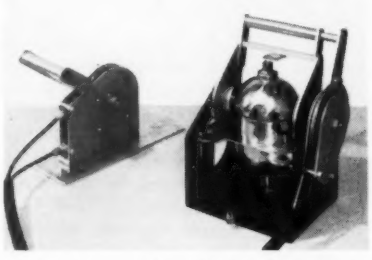
The new unit, available in eight sizes, offers advantages of resistance to acids, alkalis, and solvents, high thermal conductivity and low pressure drop. They are of robust construction, light in weight and occupy considerably less space than is normal for equipment of equivalent performance.

Tick **No 209** on reply card

SOURCE CONTAINERS

industrial applications

Two new containers have been introduced by Gammax for radiographic work. Weighing 12 lb and 37 lb, these are designed to hold sources commonly used industrially. The larger is for caesium-137, iridium-192 and up to 200 mc of cobalt-60, and conforms with the 'model Code of Safety Regulations (Ionizing Radiations)' issued by the International Labour Office. The smaller container is for thulium-137 and lower activities of iridium and is designed primarily for pipe line radiography.



Safety is ensured by the positive remote control available for the two sizes of Gammax isotope containers

Both these containers consist of three parts, two hemispherical lead blocks and a pencil which is housed in the upper hemisphere and which contains the source. By moving the operating handle, the upper hemisphere is rotated through 90° to expose the inner source container. For open source radiography, the inner container can be removed by a handle. Remote control can be incorporated and a built-in patent lock prevents unauthorized access to the source.

Tick **No 210** on reply card

FAST CUTTER

economy in operation

A new tool has been added to Baddeley's range of welding and cutting equipment. Known as the Lightning Cutter, it is capable of cutting thicknesses from $\frac{1}{8}$ in. to 14 in. and a full range of one piece nozzles are available for general work, stepping, riveting and gouging.

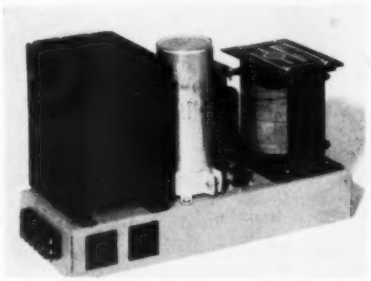
The cutter is suitable for high, medium and low pressure acetylene gases and by using the correct type of nozzles other fuel gases may be used. The gases are mixed in the cutter and so balanced that backfiring is eliminated.

Tick **No 211** on reply card

STABLE POWER SUPPLY

compact unit

A supply unit where a compact, stabilized d.c. source is required such as heater supplies in d.c. amplifiers and exciter lamps in photoelectric measuring instruments has been introduced by Allied Electronics. The basic unit, LS353-H, is a germanium junction rectifier circuit with a transistor voltage stabilizer and a reference potential device.



The Allied Electronics power unit, LS353-H, operating with a nominal voltage of 6·3 V, provides stability against mains voltage variation of ± 10%

The circuit provides a high degree of stabilization against changes in input voltage, and a low ripple content: a preset control permits variation of the output voltage over a small range. Units are available either in chassis form 4 in. × 10½ in. × 6$\frac{9}{16}$ in., or in cases.

Tick **No 212** on reply card

HIGH SPEED SCALER

optimum resolving time

Featuring both preset time and preset count, the new Tracerlab Compu/Matic scaler is an ultra high-speed scaler designed for use with geiger, scintillation and proportional detectors. It can also be used with automatic data processing equipment. The instrument provides one microsecond resolving time, front panel discriminator, precision electronic timer and either a 5000 or 2500 volt stable high voltage power supply.

The calibrated discriminator is continuously adjustable from 50 mV to two volts which allows for selection of the optimum sensitivity for the detector being employed; and in the case of proportional and scintillation counting, provides a measure of pulse height discrimination. By means of a rear switch, 25 microsecond resolving time, which is the optimum for operating geiger de-

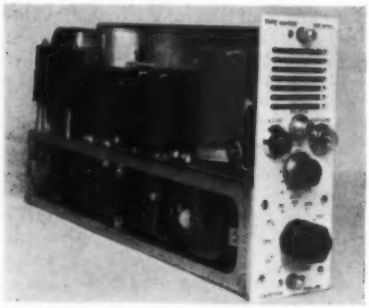
tectors without double pulsing, can be selected.

Tick **No 213** on reply card

LOW-DRIFT D.C. AMPLIFIER

suitable for multipacks

Solartron's AA 900 Wideband d.c. Amplifier has been designed for the distortion-free amplification of very low-level



With a linearity better than 0·1% to 2 kc/s, a number of 'Solartrons' AA900 amplifiers are already in use on research work in the US

signals from transducer sources such as pressure pick-ups, thermocouples or photocells.

The AA 900 has a bandwidth of d.c. to 40 kc/s (3 db) and a low equivalent input drift of less than 2 microvolts over 40 hours. Produced with integral mains power supply, six such amplifiers can be fitted into the standard 19-inch racking module.

The low figures of drift and noise achieved have been made possible by use of negative feedback techniques, including continuous 'chopper' correction. Noise and ground loop problems are minimized by holding the common voltage rail above chassis, and the input above nominal earth.

Tick **No 214** on reply card

COMMERCIAL TITANIUM

wider applications

Two new materials have been added to the range of ICI commercially pure titanium. The softest and most ductile material, ICI Titanium 115 has a maximum tensile strength of 26 tons/in² with a minimum proof stress of 13 tons/in²; the strongest, ICI Titanium 160, has a tensile strength of 40–50 tons/in² with a minimum proof stress of 30 tons/in². These will give more latitude to the fabricator of assemblies, such as vessel linings and pipework for chemical plant, in which ductility is a prime consideration, while improvements in formability of the harder grades will permit their use for more highly stressed components.

In addition, two alloys, Titanium 230 and 679 are now available in normal commercial quantities. Titanium 230, formerly known as experimental alloy EX012, is a titanium copper alloy which has been developed for applications where medium strength at moderate temperature must be combined with good weldability and formability.

Titanium 679, a high-temperature creep-resistant material, previously known as EX013A, is a complex titanium alloy containing tin, zirconium, aluminium, molybdenum and silicon. It has been developed to withstand high stresses at temperatures above 400°C and shows remarkable resistance to creep in the range 400–500°C.

Tick **No 215** on reply card

PORTABLE DETECTOR

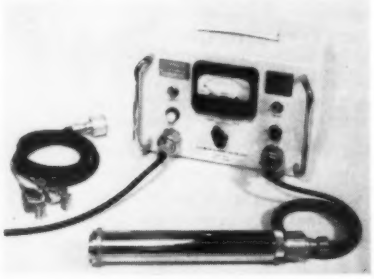
multiple applications

To detect plutonium at maximum permissible body burden level or even less, Plessey Nucleonics have developed a mains or battery-operated portable detector, the PNI 1080. This instrument is essentially a detector of low energy gamma radiation.

As well as being capable of detecting minute amounts of plutonium-239 in the human body, with slight modification and recalibration the instrument can also detect the presence of americium. Another modification enables uranium 235 to be detected.

The complete equipment consists of a detector probe connected by up to six feet of cable to an indicating unit.

The probe consists of a thin, thallium-activated, sodium iodite scintillator mounted on the end of a multiplier photo tube. A chain of resistors is mounted on the inside of the probe in order to provide the correct potential on the dynodes and a cable matching net-



Apart from its normal industrial and research applications, the Plessey Nucleonics PNI.1080 detector may be enclosed in a polythene container for use in hospitals

work ensures optimum signal pulse transfer from the probe to the indicator unit.

The indicator unit consists of a pulse amplifier, a pre-set but adjustable single channel pulse amplitude analyser, a variable and stabilized E.H.T. supply for the photo tube, and a display system. All circuits in the indicator unit use transistors.

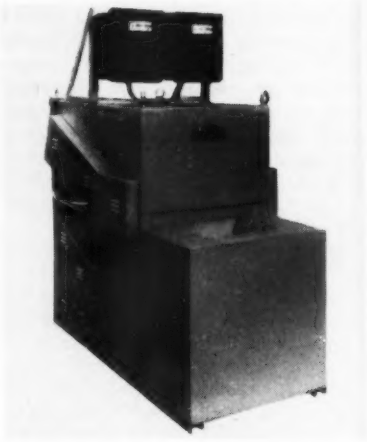
Sensitivity of the instrument for direct plutonium radiation is 15 c/s per microcurie and about 0·2% of this figure for background radiation. Maximum permissible body burden of plutonium located at one point gives about five times the background count through 1 cm of human tissue.

Tick **No 216** on reply card

ALUMINIUM FURNACE

melts and holds

An improved type of aluminium melting and holding furnace is made by Hedins. The new furnace does away with the crucible, and element replacement can be carried out without loss in production. Heating is by means of silicon carbide rod type elements radiating down onto the metal. In operation, standard billets are fed into the melt section whence the molten metal runs down into



The Hedin aluminium furnace can be used for melting and/or holding purposes at the rate of 5 lb of metal per kWh

the holding bath, where it is maintained at the required temperature.

The standard range provides furnaces with a throughput of 125, 250, 500 and 1000 lb aluminium per hour. The metal is thermostatically maintained at the correct temperature to produce a metal of high purity and to reduce to the minimum metal losses through oxidization and volatilization.

Tick **No 217** on reply card

MINIATURE SWITCH

high temperature operation

Designed for continuous service in temperatures as high as 600°C Burgess have introduced their VH3 miniature microswitch which is suitable for use under radioactive conditions.

It is made entirely of compatible materials; stainless steel for case and

mechanism, Nimonic-90 for coil spring, aluminium oxide for base and operating plunger and platinum for contacts.

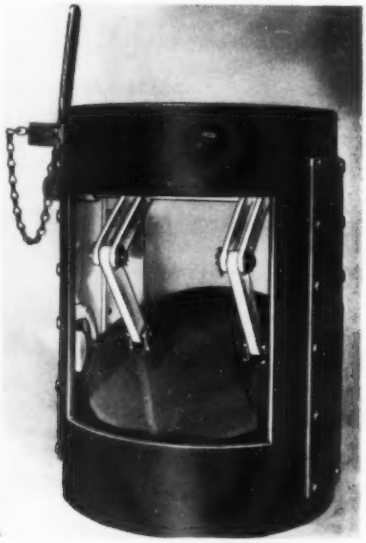
The VH3 is a single pole, double throw microswitch which will make, break or changeover currents in the order of 1 amp at 250 volts a.c. or 30 volts d.c. Operating force is 16 oz. maximum and movement differential is 0·016 in. maximum.

Tick **No 218** on reply card

LARGE GAS VALVES

rapid closure

For use on gas ducts or large-sized ventilating systems, the Ventseal valve provides an efficient emergency sealing device. It can be closed manually from



Already approved by the MOT and Lloyd's for marine applications, the Ventseal valve is now being incorporated in chemical plants

the fully open position in three seconds. This type of valve is available in sizes from 10 in. to 36 in. diameter and is fitted with a resilient sealing ring which mates with a flange lip in the duct to provide total closure. Remote control operation can be incorporated for single or groups of these valves.

Tick **No 219** on reply card

LINEAR COUNT RATE METER

X-ray applications

This Hamner instrument, N-730, has been designed for counting and monitoring duties in the nuclear research field, reactor water supply systems, and especially for X-ray instrumentation as used in analytical chemistry and petroleum industry research laboratories and refineries. Providing direct counting of pulses it has a range of 10 to 50,000 c/s with nine intermediate linear ranges from

The Hamner Linear count rate meter, N-730, has space so that a binary plug-in with a resolving time of less than 10 microseconds can be included to extend the range to 100 kc

0 to 5000. The decade scale of 10 with 1 microsecond resolution extends the range one complete decade. It has an output for a standard 10 mV recorder. Output accuracy is $\pm\frac{1}{4}$ division on a 10 mV recorder with a scale of 100 divisions.

Tick **No 220** on reply card

LOW-FILTRATION X-RAY TUBE

biological application

A low-filtration X-ray tube has been developed by Müller. This is a new dual-focus tube and shield, rated at 150 kV, with a beryllium window.

The tube meets the requirements of the plastics, rubber and light alloys industries where a very low filtration tube is required if the best results are to be obtained. It may also be used for the irradiation of biological specimens, as the X-ray output is considerably higher than that of conventional tubes of similar ratings. It is claimed that, at the present time, this is the only 150 kV tube with a filtration of 3 mm of beryllium available.

So as to achieve a high irradiation intensity in biological work, the distance between X-ray port and focal spot has been kept as short as possible. A minimum distance of 70 mm can be obtained between focal spot and the sample and by removing four screws and taking off the snap lock and baseplate, the focal spot can be brought to a minimum distance of 33 mm from the sample.

Tick **No 221** on reply card

IN BRIEF

To handle slurries. A new range, the type DO, of Monobloc centrifugal pumps have been introduced to handle viscous liquids and liquids containing small solids. Capacities of from 10 to 360 gal/min and heads up to 86 ft, depending on capacity, are available.

Tick **No 222** on reply card

Demineralized water. Where comparatively small but readily available supplies of high quality demineralized water are required, mixed bed Deminrolit plants, drawing their supply from mains water, can now be used.

Tick **No 223** on reply card

Miniature square meters for space saving on panels are now made by Baldwins. The range covered for d.c. is from 50 micro-amps to 100 amps and from 50 millivolts to 300 volts or for a.c., the range is between 50 micro-amps to 20 amps and from 5 volts to 300 volts.

Tick **No 224** on reply card

Automatic weighing. For industrial use on hoppers, conveyors or loading platforms Elcontrol have developed an automatic system. The equipment uses one, two or three load cells connected to a remote relay which integrates the output from the cells. Units suitable for weighing between 50 lb and 1000 tons are provided.

Tick **No 225** on reply card

Light source. A monochromator, using a plane grating as the dispersing element, has been introduced by Hilger & Watts for laboratories requiring a simple light source of variable wavelength, between 200 and 1000 mμ.

Tick **No 226** on reply card

Vibrating drive motors. Jointly made by English Electric and Grantham Electrical a range of completely self-contained units operating at 1500 rev/min synchronous speed and with an output of up to 7500 lb centrifugal force, or 10,000 lb at 3000 rev/min, are now available.

Tick **No 227** on reply card

Latched relay. Simmonds have introduced a new relay which by employing a remanent core, remains latched after being energized, until it receives a pulse in the opposite direction. It withstands considerable shock and vibration conditions.

Tick **No 228** on reply card

Electronic components. Smith have developed a comprehensive range of BNC connectors and adaptors, small a.c. motors, synchros, generators and gyros.

Tick **No 229** on reply card

For small TV monitors. RCA have introduced a new rectangular glass monitor kinescope, RCA-8HP4, for small TV equipment. An external conductive coating may be utilized to provide a supplementary filter capacitor.

Tick **No 230** on reply card

Super-sulphated cement. Lafarge are now marketing the first British-made cement of this type. It is very resistant to sulphates, sea-water, oils, fats and dilute acids.

Tick **No 231** on reply card

Self luminous signs. A new range of Permluco light sources and signs for emergency use in event of power failure are now available.

Tick **No 232** on reply card

INDUSTRIAL NEWSDESK

Harwell's new facility

The new Neutron Project Laboratory at AERE, Harwell, was brought into operation on November 5. The principal component of this experimental facility is a neutron time of flight spectrometer, basically a two stage intense neutron source. The first stage consists of a travelling wave linear accelerator, installed by Metropolitan Vickers Ltd., which produces bursts of electrons that have been accelerated up to an energy of approximately 30 MeV. These bursts are normally ¼ microsecond in duration, carry an electron current of between 0·3 and 0·4 amp during the burst and occur at a rate of up to 750 pulses per second. The electrons fall on a mercury target which serves the dual purpose of producing X-rays and removing the heat caused by stopping the beam.

In the second stage the X-rays are absorbed in uranium to produce neutrons by photodisintegration and photofission. The sub-critical reactor used as a target was designed and built at AERE and uses highly enriched uranium as fuel. During the pulses the fissionable assembly is reacting at about 8 MW power, although due to the pulsed nature of the source, the mean power will never rise above 2½ kW. Extensive electronic apparatus has been installed to time the flight of the neutrons and speeds between 500 m/s and 5,000,000 m/s will be recorded with an accuracy of one-tenth of a microsecond.

The containment building has been designed to permit the use of a large number of beams of neutrons so that several experiments may be performed simultaneously. Already twelve experiments have been laid out in the area surrounding the building. Future plans include the construction of a longer flight tube 300 metres in length.

This equipment will be used under the supervision of the Nuclear Physics Division of AERE for research in nuclear physics and reactor physics and will enable neutron cross-section measurements of much higher accuracy to be made than have previously been possible.

ICI sell out

Rio Tinto and Dow Chemie AG, the Swiss subsidiary of the Dow Chemical Company, have jointly acquired the share capital of Thorium Ltd. from Imperial Chemical Industries Ltd. and Howards & Sons Ltd. and the management has been assumed by the Rio Tinto Management Services (UK) Ltd.

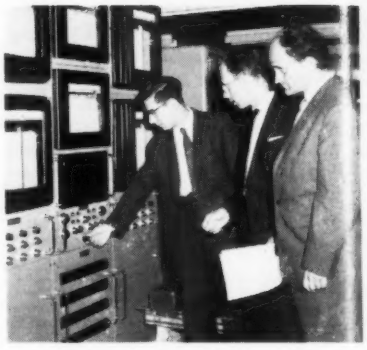
Thorium Ltd., founded in 1914 and with works at Widnes, is the principal processer of crude thorium materials in the UK and besides meeting most home demands for thorium oxide and salts, is an exporter of these materials. The majority of the output is of cerium compounds although a variety of rare earth compounds is also produced.

This is not the first cooperative effort by Rio Tinto and Dow as they have been associated since the formation in 1958 of Rio Tinto Dow Ltd. This Canadian company is producing crude thorium salts from the treatment of the barren liquors resulting from uranium extraction at Rio Tinto's Algom Quirke mine, Ontario. This Rio Tinto thorium plant which came into production in May 1959, is the first of its kind in the world to employ a solvent extraction process.

Giant probe carrier

A remotely controlled instrument bridge, weighing nearly 27 tons, has been installed at the AEC's National Reactor Testing Station in Idaho and will be used shortly to accurately position radiation-measuring probes in two large fuel ponds. Built by the Nuclear Equipment Dept., Mechanical Division of General Mills, it will be employed by the Aircraft Nuclear Propulsion Dept. of GE under AEC and USAF contracts for testing and evaluating shielding materials for use in aircraft.

Moving on 90 ft. precision rails with internal gear racks, the bridge will span two pools and a remotely controlled mast will operate in the 30 ft. deep water. Instrument standards have been used in the manufacture of the mechanical components and an automatic positioning system, incorporating an analogue-to-digital encoder, has been included in the mechanism. The control system can be preset to move the mast automatically to any position in either pool.



MONITORS FOR GERMANY. During initial acceptance tests of BSD equipment for Karlsruhe at Plessey Nucleonics, the timing units were examined by (l to r) Mr. K. W. Cunningham of Plesseys, Herr Kraus and Dr. Saufferer, both of Kernreaktor GmbH

Going to overseas markets

Orders for five Wiggins dry seal gasholders to be supplied to India have recently been received by member companies with the Power-Gas Group. Four of these units are for the Indian Atomic Energy Establishment and will be manufactured in India, special items only being supplied from the UK.

To take advantage of the European Common Market a Belgian-American company, Auriema-Europe SA, has been formed in Brussels by Ad. Auriema Inc. and Ets. N. Blomhof. This new organization will operate directly with US manufacturers.

Continuing their plans to expand their European sales organization, Texas Instruments Ltd. have recently appointed distributors in Brussels, Darmstadt, Oslo and Turin. This brings the total of Texas' centres for semiconductor devices in Western Europe up to eight.

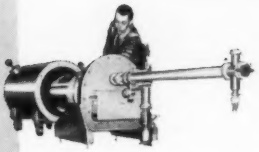
Looking to the time when a reactor

RADIOGRAPHY AT HINKLEY POINT. Welds on the twelve Babcock & Wilcox boilers are inspected on site before erection. For this purpose a 250 kV mobile Marconi X-ray equipment is used

VERSATILE ACCELERATORS for fundamental or applied NEUTRON RESEARCH

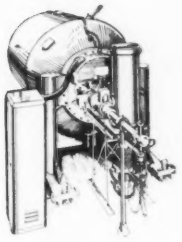
●

NEUTRON SOURCES now available from High Voltage Engineering Corporation range from compact, low-cost Van de Graaff positive-ion accelerators to large linear electron accelerators for energies up to 100 Mev and higher.



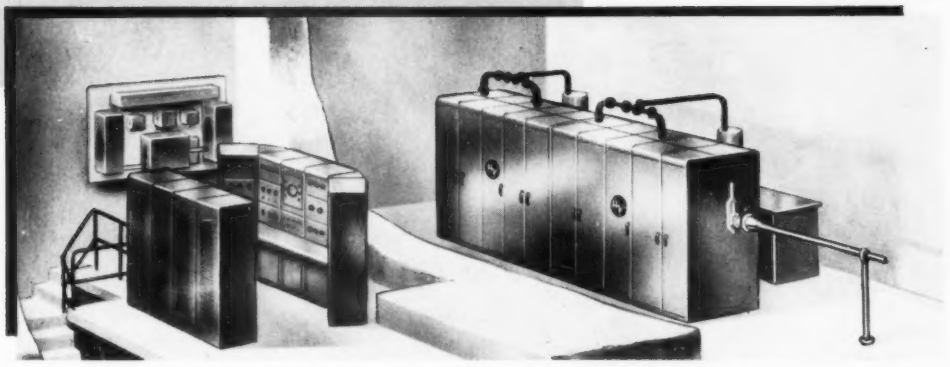
PN-400 Van de Graaff — Lowest cost. Ideal for reactor engineering, nuclear training courses, pulsing subcritical assemblies.

Pulsed or continuous operation.



KN Van de Graaff — Powerful and precise for broad research programs including nuclear physics, advanced neutron work, biology, reactor engineering, and activation analysis.

Pulsed or continuous operation.



LS Series Linear Accelerators — Electron energies of 6 Mev and above. Optimum neutron yield per kilowatt obtained above 30 Mev. Useful for nuclear physics, neutron-damage studies, time-of-flight research, high-energy radiography. High flux density suitable for isotope production.

Model	Particle Energy Mev	Pulse Current milliamperes	Total Neutron-yield Rates during Pulse	Pulsing and Repetition Rates
PN-400	0.4	0.10	10^{10} n/sec †	μsec range 1-10,000 pps
KN	3	0.40	2×10^{12} n/sec ‡	millimicrosecond to μsec range; 1-10,000 pps
LS Series Example	40	350	10^{14} n/sec *	0.01-10 μsec 1-2500 pps

† T(d, n) He^4 reaction
‡ Be^9 (d, n) B^{10}

* Photo-nuclear and photo-fission reactions.

Other accelerators rated for operation at intermediate and higher outputs, are also available. Write High Voltage Technical Sales Department for specific performance data

HIGH VOLTAGE SERVICING COMPANY LTD.
60 Carpenters Wood Drive
Chorley Wood, Herts.
Telephone Field End 7431

HIGH VOLTAGE ENGINEERING
CORPORATION
BURLINGTON, MASSACHUSETTS, U.S.A.

Tick **No 84** on reply card for further details

will be built in Eire, John Thompson Instrument Co. have appointed the Accurate Instrument Co. of Dublin as their Irish agents. They will doubtless have a 'watching brief' for the other companies in the John Thompson Group.

Anticipating that the Euratom programme will lead to increased demands for American monitoring and nuclear instrumentation, Mr. S. S. Auchincloss, President of Tracerlab, has made an extensive tour of European cities. At the same time he spent a period in Amsterdam where manufacturing operations by Tracerlab's European subsidiary are now getting under way.

Large scale sintering

Westinghouse Electric have developed a new process, known as continuous powder compaction, which makes it possible to construct large items from tungsten, molybdenum and other strong, high-temperature metals and alloys. Metal powders are compressed into large uniform metal bars and following 'baking' in an oven, these are manipulated by standard metal-working procedures. This technique is equally applicable to non-metallic ceramic powders.

Until the introduction of this process, attempts to prepare large bars, strips or sheets from powders proved expensive, cumbersome and technically difficult to achieve. For these reasons, only small objects which could be pressed directly into their final exact shape had been previously made from powders on a commercial scale.

UK prices coming down

Philips universal lead castle components have been reduced in price by almost 50%. These castles are suitable for use with many types of Geiger Müller counters, scintillation and proportional counters with diameters up to 80 mm. Lead shielding, 35 mm thick, considerably lowers background radiation.

Another Philips product now subject to a price reduction of some 15% is their valve voltmeter.

Smiths Aviation Division has introduced considerable reduction for quantity orders covering a range of components. This covers synchros, servomotors, degree counters and micro-relays. Improved production methods have enabled reductions of between 10 and 50% to be made, depending on the number and type of unit ordered.

Also due to streamlining production methods, British Central Electrical Co. Ltd. have made substantial reductions in the price of their Infini-Angle lighting units used for inspection and laboratory purposes.

Expansion in Britain

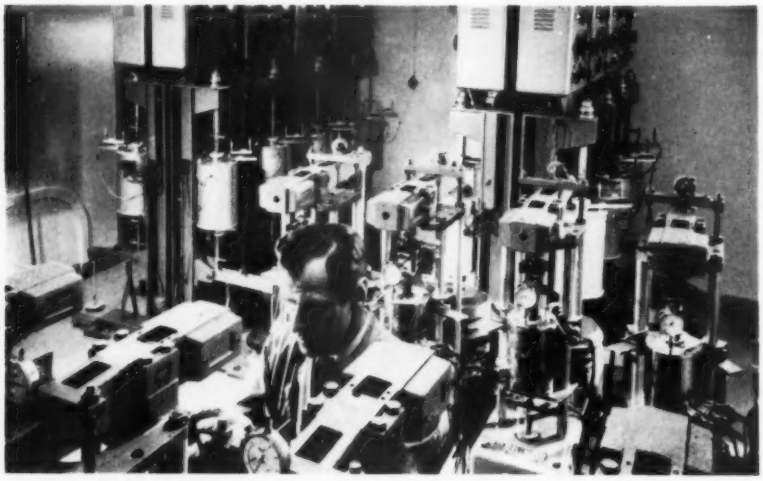
Hilger & Watts Ltd. have acquired the whole of the issued share capital of The Infra-Red Development Co. Ltd. The technical and manufacturing resources of Hilger & Watts will be used to expedite development of gas analysers in the field of process control.

Progress with the Gresham unit sequencing system, developed earlier this year, has been so rapid that a separate company, Gresham Automation Ltd., has been formed. Already the new organization is concerned with the automation of several chemical plants for the USSR.

A new division has been set up by Research & Control Instruments Ltd. known as the Industrial Products Division. Henceforth it will be solely responsible for Philips industrial equipment which includes arc welding supplies, filtration equipment and high frequency heating generators.

Electro-Hydraulics Ltd., a company in the Owen Organization, has taken over Scott Electric Vehicles Ltd. This will enable the *Conveyancer* range of material handling equipment to be greatly extended and it will now include electronically guided trucks.

Lancashire Dynamo Electronic Products Ltd. have introduced a planned maintenance scheme for their clients' installations in the UK. Four visits per annum will be made to check performances and ensure that the original standard of operation is maintained.



DEVELOPING BOILER EFFICIENCY IN SWEDEN. At the Sandvik Steel Works comprehensive research is being carried out by continuously testing alloy steels under high temperature conditions up to 700°C for between 10,000 and 25,000 hours

Electronic building bricks

Mullard Equipment Ltd. recently held a five-day private exhibition in London to introduce their ranges of standard electronic 'building bricks' for industrial control systems (see *New Products Survey*, October). The interest shown in these components was reflected by the fact that some 1600 applications for tickets were received. Included in the exhibits was a tape punch drive unit which has been designed to drive a tape punch from the output of Mullard's L.281 analogue to digital converter. A similar unit coordinating 80 temperature recording points is at present halfway through a six month trial at Dounreay where it is being used in conjunction with the DMTR.

Large order from AEA

EMI Electronics Ltd. have been awarded a contract for 43 hand and clothing monitors. Similar units have already been ordered by Germany, Belgium, Irsael and Australia. This type of unit is part of the Emirad range of nuclear health instruments and is capable of monitoring both hands simultaneously for alpha and beta contamination. This reduces the hand count to five seconds and at the same time the instrument can check two other person's clothing and footwear.

Visible and audible warnings operate immediately the maximum permissible level of contamination is exceeded and as an automatic compensation for background radiation is incorporated, these monitors can be sited at the most convenient location, regardless of nearby radioactive materials.

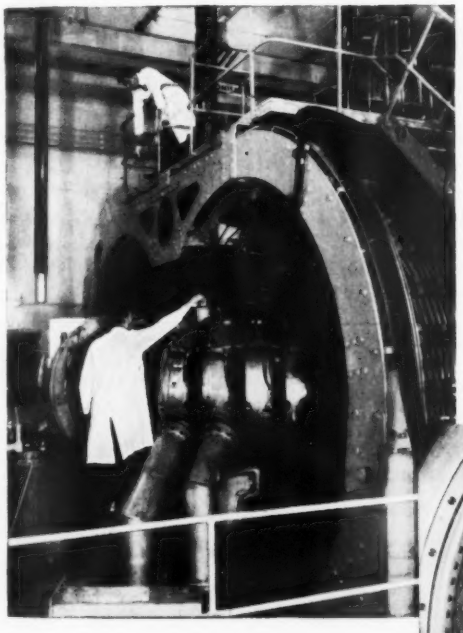
US industry consolidates

Over the past month several leading American companies have announced amalgamation plans. Aerojet-General Nucleonics have merged with the Turbo-Machinery Division of Aerojet-General Corp. As the Turbo-Machinery Division has developed turbines and pumps for operating under extreme conditions, this merger will greatly increase Aerojet's

TEDDINGTON BELLOWS
and Nuclear Power
HARWELL PAYS A TRIBUTE

Harwell top research scientists have freely acknowledged * that recent improvements in the operational efficiency of Zeta owe much to the introduction of a corrugated stainless steel liner inside the aluminium 'torus'. Having decided to use such a liner, they turned to Teddington engineers who, out of their experience in adapting their bellows expansion joints to various demands in a wide field of industry, produced exactly what was required for satisfactory running over long periods.

* *In a paper read before the I.E.E. on 29/30 April 1959 by Mr. J. T. D. Mitchell of the U.K.A.E.A., Harwell*



In Zeta, experiments towards controlling fusion have resulted in gas temperatures of several million degrees centigrade being achieved for millisecond periods. View showing the torus.

This stainless steel liner has improved operational characteristics and requires less maintainance than the original aluminium liner system. Here is part of the twelve welded sections of Teddington stainless steel bellows tube of wall thickness 0·017"; it has 2½ convolutions per inch of a depth of 0·75". The bellows is 38 inch bore and the whole toroidal bellows assembly has an axial length of 37 feet and an electrical resistance of 0·02 ohms.

SEND FOR HANDBOOK
R. 123

Illustrated descriptions are given of the many and varied problems that Teddington Bellows Expansion Joints can overcome. If you did not secure your copy at the Engineering Exhibition, please write for one.

ZETA

Teddington Bellows are produced in technical collaboration with the Solar Aircraft Co., U.S.A.

TEDDINGTON
STAINLESS STEEL BELLOWS

TEDDINGTON AIRCRAFT CONTROLS LTD. (*Industrial Bellows division*)
Ammanford, Carms. Tel.: Ammanford 2255

DUST SUPRESSION AT AEA's SPRINGFIELDS WORKS. Pneumatic engineering for cleaning and reclamation is used on a large scale and in the case of pressing pellets of uranium tetrafluoride and magnesium powder, complete removal of radioactive waste is handled by the BVC cyclone on the right

capabilities to undertake the development of complete nuclear power systems.

Vitro Chemical Company, a subsidiary of Vitro Corporation of America, has been formed to consolidate operations in the US of Vitro Uranium Co., Heavy Minerals Co. and Vitro Rare Metals Co.

In brief

Activities halted. The US Atomic Energy Commission has issued an order to X-ray Engineering Co. partially suspending their licence to use radioisotopes in industrial radiographic work. It is claimed that the company have not been using radiation survey instruments on site.

Tests completed. Rocol Molytone 265 Grease has withstood irradiations of 7×10^8 rads without deterioration at Calder Hall and has been approved for charge machines lubrication.

D_2O know-how. The AEC have recently made available 39 additional reports covering the production of heavy water by the dual-temperature hydrogen sulphide exchange process.

Pace for Germany. The Deutsches Elektronen-Synchrotron, Desy at Hamburg-Bahrenfeld has ordered a Type 231R analogue computer from the European Division of Electronic Associates Inc.

Lead the enduring metal. This is the title of a film recently made by the Lead Development Association. Considerable part of it describes radiation shielding in nuclear establishments and hospitals.

New gamma standards. The US National Bureau of Standards have now made available three new gamma-ray radioactivity standards. They are strontium-85, niobium-95 and mercury-203, which can be obtained in approximately 5 grams of solution, sealed in glass ampoules.

More lithium. Industrial sales of lithium are expected to increase by at least 20% during the last quarter of 1959 and substantial increases are also anticipated in 1960, states the Lithium Corporation of America.

TV for Berkeley. AEI-John Thompson Ltd. have ordered two sets of reactor inspection television camera equipment from Pye Ltd. for use at Berkeley.

LOOKING AHEAD

TUESDAY 1—WEDNESDAY 2 DECEMBER
Conference on the industrial uses of radioisotopes, AEC, Detroit Nuclear Council and Engineering Society of Detroit. Applications to Greater Detroit Board of Commerce, 320 West Lafayette St, Detroit 26, Michigan, USA
Conference on Industrial Isotopes, Florida Nuclear Development Commission and US Atomic Energy Commission at Miami, Florida, USA

WEDNESDAY 2 DECEMBER
Annual General Meeting. The British Institution of Radio Engineers 6.00 at London School of Hygiene and Tropical Medicine, Keppel St, Gower St, London, WC1

THURSDAY 3 DECEMBER
An Introduction to Electronic Data Processing Dr. H. A. Thomas, DSc, MSc, MIEE, SMIRE, the Institution of Plant Engineers 7.00 at The Royal Institution, 21 Albemarle St., London, W1. Application for tickets to L. R. Leworthy, Esq., Chairman London Branch Papers Committee, The Institution of Plant Engineers, 2 Grosvenor Gdns., London, SW1

THURSDAY 3—SATURDAY 5 DECEMBER
Meeting of the Division of Plasma Physics. American Physical Society at Monterey, California, USA

FRIDAY 4 DECEMBER
Nuclear Magnetic Resonance (Discussion) Institution of Electrical Engineers 6.00 at Savoy Place, London, WC2
Remote Supervisory Control and Plant Monitoring L. S. James, the Society of Instrument Technology 5.30 at the Administration Building, Esso Refinery, Fawley

MONDAY 7 DECEMBER
Electro-Magnetic Flow Meters L. M. Bennet. The Society of Instrument Technology, 7.00 at The University, St. George's Sq., Sheffield, 1

TUESDAY 8 DECEMBER
Instrumentation of the Dounreay Reactor K. R. Sandiford, BSc, the Society of Instrument Technology 6.45 at the Manchester Room, Central Library, St. Peter's Sq., Manchester, 1
Generation of Electrical Power from Nuclear Sources W. G. Busbridge of AERE, Institution of Plant Engineers 7.15 at the Engineers' Club, Albert Sq., Manchester

THURSDAY 10 DECEMBER
The Simulation of Nuclear Reactors and Power Plants W. J. G. Cox and J. Dowsing, British Institution of Radio Engineers 6.30 at the London School of Hygiene and Tropical Medicine, Keppel St., London, WC1

FRIDAY 11 DECEMBER
Radioactive Isotopes in Industry W. G. Busbridge. The Society of Instrument Technology, 7.00 at the Lecture Theatre of the Byng Kendrick Suite of the Gosta Green College of Technology, Aston St., Birmingham

TUESDAY 15 DECEMBER
Data Handling Problems in Atomic Installations (Discussion) Institution of Electrical Engineers 5.30 at Savoy Place, London, WC2
Magnetic Recording Techniques Half-day Symposium The British Institution of Radio Engineers 3.00 London School of Hygiene and Tropical Medicine, Keppel St., London, WC1
Some Aspects of Marine Reactor Security K. Maddocks, BSc, Joint Panel on Nuclear Marine Propulsion 5.30 at the Institute of Marine Engineers, Memorial Bldg., 76 Mark Lane, London, EC3

WEDNESDAY 30 DECEMBER
Energy from the Atom Prof. C. F. Powell, MA, PhD, ScD, FRS, Institute of Marine Engineers 7.00 at the Birmingham and Midland Institute, Paradise St., Birmingham

1960

MONDAY 4 JANUARY—FRIDAY 29 APRIL
No. 20 Harwell Reactor Course. Applications to the Principal, Reactor School, AERE, Harwell, Didcot, Berks

TUESDAY 5—THURSDAY 7 JANUARY
Recent Mechanical Engineering Developments in Automatic Control (Symposium) The Institution of Mechanical Engineers, applications to the Secretary, 1 Birdcage Walk, Westminster, London, SW1

WEDNESDAY 6 JANUARY
Non-destructive Testing E. McCabe, Institution of Electrical Engineers, Southern Centre, 6.30 at CEEB Offices, Portsmouth

MONDAY 11—SUNDAY 24 JANUARY
Effects of Atomic Radiation. Scientific Committee of the General Assembly at UN Headquarters, New York, USA

LOOKING FURTHER AHEAD

WEDNESDAY 2 MARCH
The Role of Formal Education and Training in Nuclear Power Developments (Discussion) The Institution of Mechanical Engineers 6.00 at 1 Birdcage Walk, Westminster, London, SW1

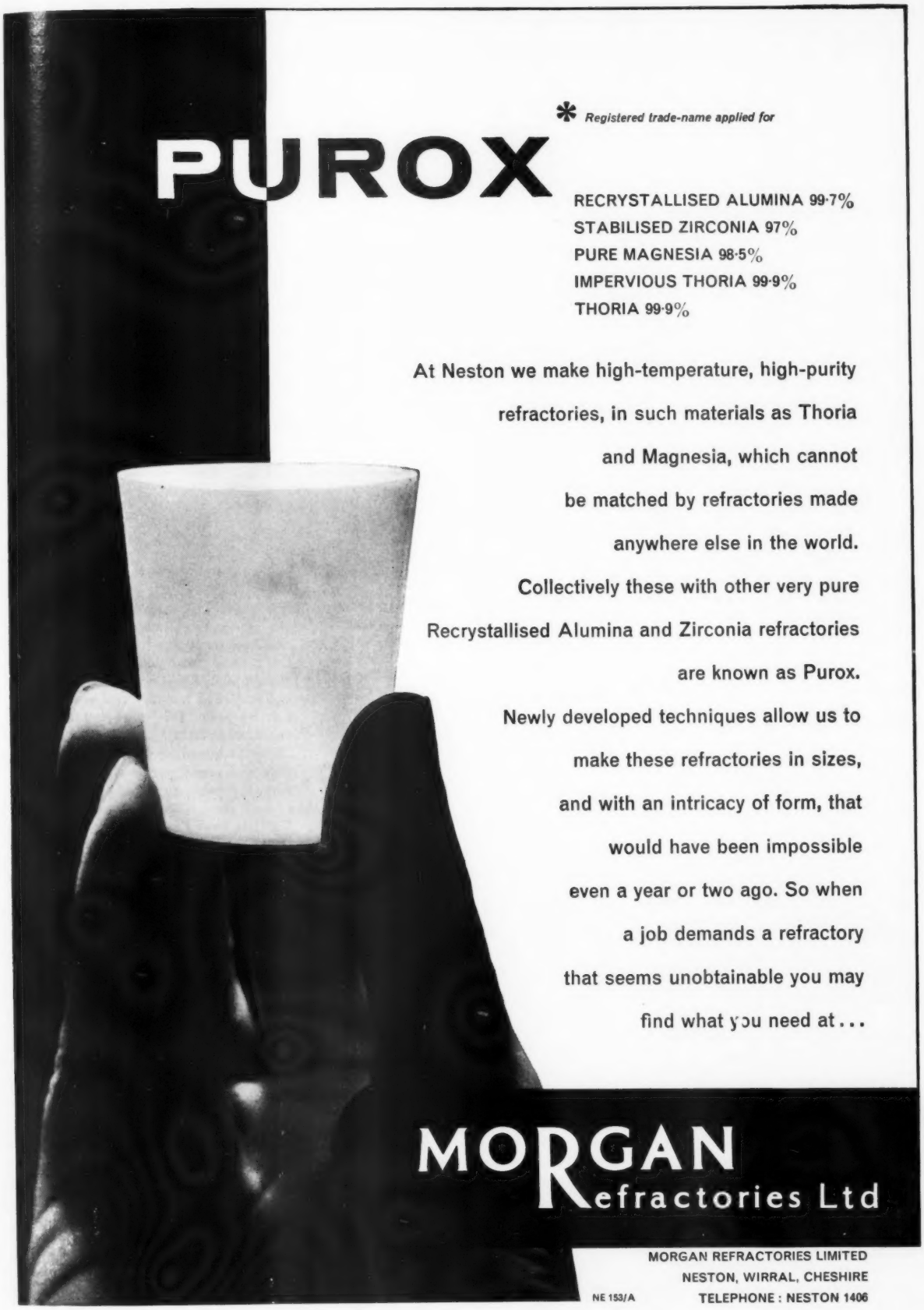
SUNDAY 3—FRIDAY 8 APRIL
Sixth Nuclear Congress, Nuclear Engineering Conference, International Atomic Exhibition and Eighth Atomic Energy in Industry Conference at New York, USA

TUESDAY 5—SATURDAY 9 APRIL
Ninth Electrical Engineers' Exhibition at Earls Court, London, SW5

WEDNESDAY 6—SATURDAY 9 APRIL
International Mineral Processing Congress and Exhibition at Church House, Westminster, London, SW1

TUESDAY 19—FRIDAY 22 APRIL
International Symposium on the Metallurgy of Plutonium. Session on Nuclear Fuels, Société Française de Métallurgie and French Atomic Energy Commission at Grenoble, France

FRIDAY 29—SATURDAY 30 APRIL
Convention on Thermonuclear Processes. The Institution of Electrical Engineers at Savoy Place, London, WC2



* *Registered trade-name applied for*

PUROX

RECRYSTALLISED ALUMINA 99·7%
STABILISED ZIRCONIA 97%
PURE MAGNESIA 98·5%
IMPERVIOUS THORIA 99·9%
THORIA 99·9%

At Neston we make high-temperature, high-purity refractories, in such materials as Thoria and Magnesia, which cannot be matched by refractories made anywhere else in the world. Collectively these with other very pure Recrystallised Alumina and Zirconia refractories are known as Purox. Newly developed techniques allow us to make these refractories in sizes, and with an intricacy of form, that would have been impossible even a year or two ago. So when a job demands a refractory that seems unobtainable you may find what you need at...

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NE 153/A

They said... In Canada this month

points from papers, speeches, conferences

Conflict over Canadian plans

A controversy was sparked off by Mr. Winnett Boyd, President of Winnett Boyd., Ltd., recently, when he seriously criticized the policy of Atomic Energy of Canada Ltd. in an address to the Ottawa branch of the Engineering Institute of Canada.

Advocating a careful reappraisal, Mr. Boyd said that Canada's problem was to choose the reactor type best suited to her particular needs and likened the cost of making a mistake to that which occurred when the Ontario Hydro had to spend six hundred million dollars in converting part of its system from 25 to 60 cycle electricity supply. Developing this idea he went on to say that immense sums will be wasted if power stations are built which cater more to the desires of the scientists than to the economic facts of life. 'It is my contention that Canada's present nuclear programme is leading us in this direction. By concentrating her efforts on a heavy water reactor, which has good nuclear characteristics, it may be that Canada is going to conduct a very expensive but interesting experiment rather than build a practical power plant.'

Canada, Boyd said, became involved with heavy water because while the English liked it, they did not have any and due to the war conditions thought it expedient to transplant the UK work on heavy water, along with the majority of its personnel to Canada. Thus at the end of the war, he remarked, we had the Americans using graphite moderated reactors to produce bomb plutonium and the UK and Canada working on the development of a heavy water reactor.

CANDU costs wrong ?

Nationalism should be avoided, Mr. Boyd went on to say, and the best type of reactor for power generation should be made on objective scientific and engineering grounds rather than because more technical experience has been had with one type of reactor than with the others. He thought that it was significant that in the US, in spite of having the only heavy water production plant in the free world, heavy water reactors were almost completely absent from the serious development programmes under the direction of the US Atomic Energy Commission.

He levelled criticism against the pumping systems and associated safety arrangements necessary when using heavy water and seriously doubted whether the capital and fuel costs for a CANDU power station would result in power costs competitive with those of coal fired plants in Southern Ontario. He based this opinion on the fact that recent American estimates for similar equipment were considerably higher and that the fuel fabrication charges are in the order of twice those predicted for the CANDU fuel elements.

Suggested changes

After reviewing possible future general lines of development for all types of applications—PWRs for marine use; BWRs and OCDRs for small and medium land stations—Mr. Boyd said 'for very large base load central power stations, with the ability to handle short, sharp peaks, I predict that the high temperature, gas-cooled, ceramic-fuelled, graphite-moderated nuclear steam generator, combined with appropriate steam accumulators, will eventually become the dominant type.' He suggested that Canada should seek to coordinate her entire nuclear programme with that of the UK. A possible way in which this cooperation could work was to establish an enrichment plant to meet both Canada's and the UK's possible future needs.

Like the UK, Canada is pretty firmly wedded to a one-type reactor programme, but a recent contender against the heavy water concept is the Daniels-Boyd high-temperature gas-cooled reactor. Its designer, Winnett Boyd, and the champion of the official view, J. L. Gray, recently agreed their cases in public speeches.

After reiterating his doubts as to the feasibility of the CANDU type of reactor and praising his own design, Mr. Boyd said 'as scientists and engineers we produce many ideas. As human beings we then become to some extent emotionally attached to our brain-children. So enamoured with them do we become that we frequently completely lose our sense of perspective. We will then sometimes fight fiercely and even recklessly for them . . . but when we get caught up in a situation which allows no escape without loss of prestige, the result can be tragic.' In his closing remarks, Boyd recommended that before it was too late, the Canadian Government should appoint an impartial investigating committee, and to prevent any undue bias, it would possibly be better if non-Canadians were employed for this difficult task.

Elegant but dangerous

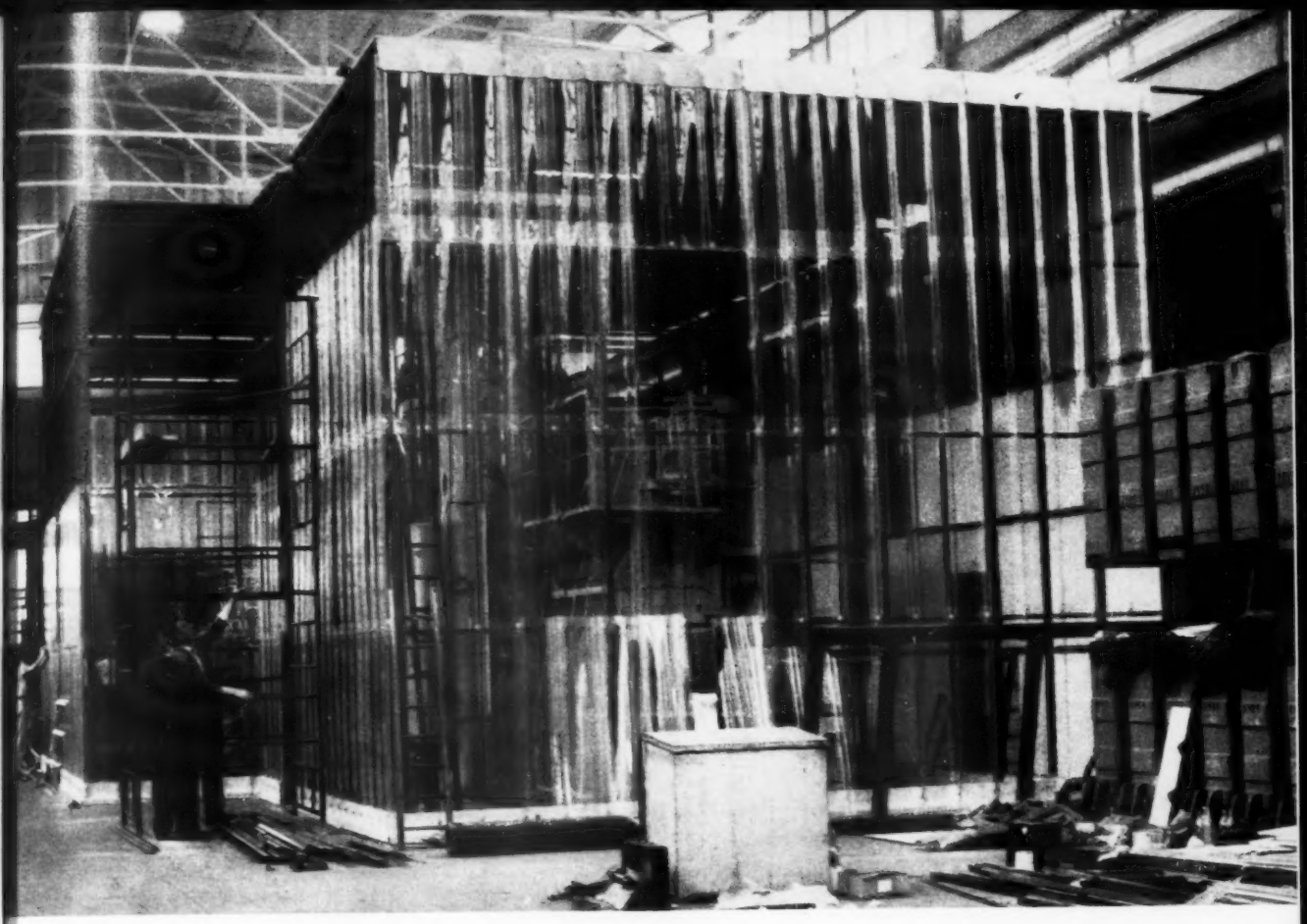
Mr. Boyd's speech provoked a vigorous reaction from Mr. J. L. Gray. In a public reply, the president of Atomic Energy of Canada strongly defended his company's present policy. Before answering the detailed points he said that he and his technical staff had looked at the design Mr. Boyd was trying to sell and while admitting that it incorporated 'some elegant and intriguing design concepts' there were some very formidable development problems; also some hazard considerations which alone could make the design unacceptable. He went on to say, 'if Canada were to embark on the high temperature, gas cooled route similar to this particular design proposal (Mr. Boyd's), we would not be building a power reactor until the late 1960's.'

Referring to Mr. Boyd's implications that the UK had originally been heavy water-minded but had changed to gas-cooled projects, Mr. Gray said this was not correct and that 'the UK started on the gas-graphite system following the war because it was the only route open. . . . They have successfully developed this system to the point where they are building large nuclear stations on a commercial basis. They have not turned to considering other types until just recently because they have enough experience and sagacity to realize that it is a very expensive and costly procedure to embark on a completely new route. . . . The UK have been studying large heavy water moderated power reactor systems for the last year or so (see UKAEA Annual Review, *Worldview*, August) and will be deciding shortly as to whether or not they will set up a full-scale project in this field.'

Refuting Boyd's suggestions that the UK and US were not supporting the Canadian heavy water reactor programme, Mr. Gray said that such an idea was an outright admission of ignorance. In fact, both Governments have openly declared that they agree with Canada's programme and that it should not be changed unless she were in a position to double the effort.

What of the future ?

Mr. Gray also expressed general agreement with the suggested types of reactors for marine and small or medium sized power plants but he doubted very much that a nuclear power plant would, in the immediate future at least, be used for 'short, sharp peaks' whether it was built to Mr. Boyd's designs or not.



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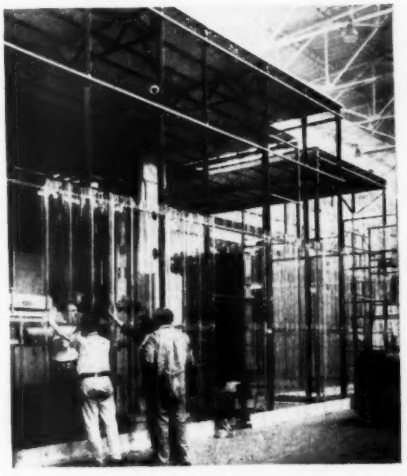

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NAMES IN THE NEWS

Mr. R. M. McKinney, a New Mexico newspaper publisher has been appointed to make a study of the United States international atomic energy programmes. Although neither a scientist nor a politician McKinney probably knows more about atomic energy in the United States

R. M. McKINNEY will study US programmes

than any other man. In 1956 he headed the committee which presented the famous 'The Impact of Atomic Energy' report to Congress and in 1957 was appointed United States representative on the board of the International Atomic Energy Agency he resigned in 1958.

The CEGB have named **Mr. C. W. A. Priest** as chief design and construction engineer in succession to **Mr. E. S. Booth** who has been appointed a full-time member of the Board.

Mr. B. D. Baines, Hawker Siddeley's senior applications engineer, has been made technical sales manager.

Dr. Erich Pohland of the German Federal Ministry for Atomic Energy has been appointed general manager of Eurochemic (European Company for the Chemical Processing of Irradiated Fuels). **Dr. R. Rometsch** has been made research director.

Mr. R. C. McCormick has joined Airtech Ltd. as chief electronics engineer. He was previously at Mullard's Research Laboratories.

To supervise the standard of their instruments Solartron Electronics have created the post of reliability engineer. First holder of the position will be **Mr. A. Cockle.**

Mr. J. M. Wild, a leading American space-age engineer, is joining General Atomics as director of Project Orion involving the use of nuclear propulsion for space vehicles.

With the appointment of Lord Hailsham as Minister for Science the Atomic Energy Office and Lord President's office will be combined. **Mr. F. F. Turnbull** will be in charge of the new office.

Mr. M. J. S. Clapham is to be chairman of ICI Metals Division from 1st January 1960. He succeeds the well-known metallurgist **Dr. M. Cook** who is retiring.

M. J. S. CLAPHAM to be ICI Metals chairman

Mr. C. W. V. Davis, a director of Research and Control Instruments Ltd. heads the new Industrial Products Division which will distribute, for Philips Electrical, arc welding supplies, filtration equipment and high frequency generators.

Mr. H. B. Dreyfus has been appointed system design and development engineer to the CEGB.

Uddeholm Ltd. have promoted **Mr. A. G. Shaw,** formerly senior Midland area representative to be area manager.

Mr. E. A. Smith has been elected to the board of Acheson Colloids Ltd., he was previously executive manager, Acheson Industries (Europe) Ltd.

E. A. SMITH for Acheson Colloids board

Mr. Airey Neave, M.P. for Abingdon, has joined the board of John Thompson Ltd.

GEC Ltd. have announced three new appointments to the board. **Mr. O. W. Humphreys** who is director of the company's laboratories at Wembley will be director for research and technical development, **Mr. T. B. O. Kerr** becomes director for finance and administration

O. W. HUMPHREYS now GEC research director

and **Mr. W. J. Bird** director for sales and marketing development.

OBITUARY

H. S. Vance, United States AEC Commissioner, died on August 31. He was 69 and was in his fifth year of service on the AEC.

CATALOGUES AND BULLETINS

Chemical catalogue. Now available Griffin & George's 1959 laboratory chemical price list includes reagents for water analysis and other specialized items.
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Tin. The summer number of 'Tin and its Uses' published by The Tin Research Institute contains an article on modifying the structure of cast-iron by additions of tin. It is suggested that the addition of tin to cast-iron leads to better wear-resistance and good machineability.
Tick **No 255** on reply card

Authority annual report. 'Atom 1959' is an illustrated summary of the UKAEA's annual report for 1958-9. Copies may be had from Government bookshops, price 2s.
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Computers. Booklet from Power Systems Computors Ltd. describes a small Blackburn analyser, large-scale transformer analogue (Blackburn) a.c. network analyser and a universal d.c. network analyser.
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Fibre filters. Technical articles and sectional diagrams are included in Mancuna's folder dealing with their new Mistex and Fumex fibre filters (*see* NUCLEAR POWER *October*).
Tick **No 258** on reply card

Reciprocating pump. Vol. 6 No. 24 of Tangye's 'One and all' includes a detailed description of a new high-pressure reciprocating pump. This covers a wider range of outputs and pressures than was previously possible and has been completely streamlined.
Tick **No 259** on reply card

Variable speed motors. Laurence, Scott & Electromotors' engineering bulletin for September has a comprehensive article on recent developments in the field of N-S motors.
Tick **No 260** on reply card

Instrument cases. Kimberley Engineering who make cases for the electronic industry have issued leaflet and standard price list.
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Book Reviews

Soviet reactors . . .

Physics and Heat Technology of Reactors Supplement No. 1, Soviet Journal of Atomic Energy, 1958 Translated from the Russian by Consultants Bureau Inc. 1959: Chapman & Hall 174 pp Price 168s.

This collection of papers can be divided into two sections, one dealing with topics in reactor physics and the other with some heat transfer problems arising in the design of reactors.

Five papers of the physics section deal with neutron diffusion theory calculations. The first two, by G. I. Marchuk, discuss multigroup methods in nuclear reactor calculations and the solution of these equations by finite difference methods; these are similar to those already discussed in the literature. However, the articles are of interest as there is a complete discussion of the validity of various interpolation schemes used for obtaining constants for multigroup equations from the slowing down equation. The other three papers deal with the relation between critical mass and volume in homogeneous assemblies for different concentrations of fissionable material, including assemblies with light hydrogen as moderator and approximate methods of calculation of neutron diffusion in hydrogeneous and non-hydrogeneous media. The error resulting from the use of age theory in the analysis of neutron slowing down is discussed.

Among a number of papers on experimental physics, an interesting one deals with the use of the pulse method to study slowing down in graphite. The approach to equilibrium of neutrons slowed down in graphite and the various techniques for measuring neutron temperature are discussed. A second paper deals with mass-spectrometer determination of the yields of various isotopes in U-233 fission. A measurement of the Xe-135 (n,γ) Xe-136 reaction cross-section for the neutron spectrum in the reactor of the Russian Atomic Power Station is reported in a paper by E. F. Makarov and Z. D. Samoilova.

Other papers deal with a variety of subjects such as the spectrum of scattered gamma radiation after transmission through a lead shield, the application of low delay thermocouples for measuring high neutron flux in nuclear reactors and the experimental determination of the maximum permissible flux of thermal neutrons.

A group of papers on heat transfer problems includes an analysis of optimum thermodynamic cycles at atomic power stations, one of the few published papers on this subject. Others deal with features of the thermal cycle in heterogeneous boiling water reactors and the design of fuel elements.

The translation is generally good, although the meaning of some translated terms is a little confusing.

J. H. Tait

. . . gamma spectra

Atlas of Gamma-ray Spectra from Radiative Capture of Thermal Neutrons by L. V. Groshev, V. N. Lutsenko, A. M. Demidov and V. I. Pelekhov. Translated by J. B. Sykes London 1959: Pergamon Press 198 pp. Price £7

The ultimate fate of most slow neutrons in a reactor is to be captured, the resulting excited nucleus then radiating the excess energy in the form of gamma-radiation. The nature of this radiation is thus of great interest in the design of shielding as well as in other aspects of reactor physics. This book is a compilation of our present knowledge of capture gamma-rays up to January 1958. The first detailed work in this field was by Kinsey and Bartholomew in Canada. Using a different spectrometer Dr. Groshev and his collaborators have made a monumental contribution to the field. Therefore a large part of this compilation represents their own data, some of it not otherwise published. The observed spectra are reproduced as well as tables of lines and level diagrams. This rather expensive book is well produced and, as well as being a demonstration of an elegant and difficult technique, can be a useful handbook for some aspects of reactor design.

E. B. Paul

. . . fusion research

Plasma Physics and the Problem of Controlled Thermonuclear Reactions Vol III Edited by A. Leontovich 1959 Translated by J. B. Sykes Pergamon Press 422 pp Price £8

The world-wide declassification of thermonuclear research in 1958 resulted in the publication of a wealth of ideas and results which had accumulated during the previous decade. The USSR Academy of Sciences published a collection of papers in four volumes; volume III has now been translated into English. It consists of 26 papers dating back to 1951, most of which are concerned with theoretical aspects of plasma containment and radiation. The experimental papers include a full account of the plasma-ring experiments of Osovets, and a description of a piezoelectric device for the measurement of plasma pressures.

Specialists in the field of controlled thermonuclear research will find this volume interesting and valuable, particularly for detailed accounts of some of the Russian work necessarily briefly reported at the 1958 Geneva Conference. It will not, however, have a great appeal for the general reader.

It is unusual to find so expensive a book reproduced directly from typescript; this is presumably justified on the grounds of speed of production. The standard of translation, as we have come to expect of Dr. Sykes, is impeccable.

P. A. Davenport

French reactor materials

Technologie des Réacteurs Nucléaires Vol 1 Matériaux by P. Ageron, A. Bonaldi, N. Gauzit and T. Reis Paris 1959: Eyrolles and Gauthier-Villars 570 pp Price Frs7120

Published in French, this is the first of five volumes which are designed to form a comprehensive reference work on the technological, theoretical, and economic aspects of nuclear engineering. The present volume, sub-titled 'Materials,' sets out to furnish information on the production, properties, and applications of nearly every substance which has been used, or proposed, for the production of nuclear plant. This data has been supported by a copious bibliography, and prefaced by two very good chapters in which basic nuclear effects and reactor theory are simply described.

It is not surprising, in view of the enormous field which the four authors have attempted to cover, that there is considerable variability in the thoroughness with which different subjects have been treated. Much attention has rightly been paid to the sections devoted to fissionable and fertile materials, and to reflectors and moderators; but it is to be regretted that little detailed information has been presented on several metals and alloys of importance in practical reactor construction. Approximately equal fractions of the book have been allocated to two groups of materials of greatly differing current importance: one chapter describes a great number of possible, but mostly highly improbable, liquid metal coolants, while the final chapter is unable adequately to describe several of the most widely-used fuel-elements canning and general structural materials.

With these reservations, it is still apparent that the book will be valuable to many classes of reader, and it could well become a standard textbook for students taking specialized courses in nuclear technology.

J. E. May

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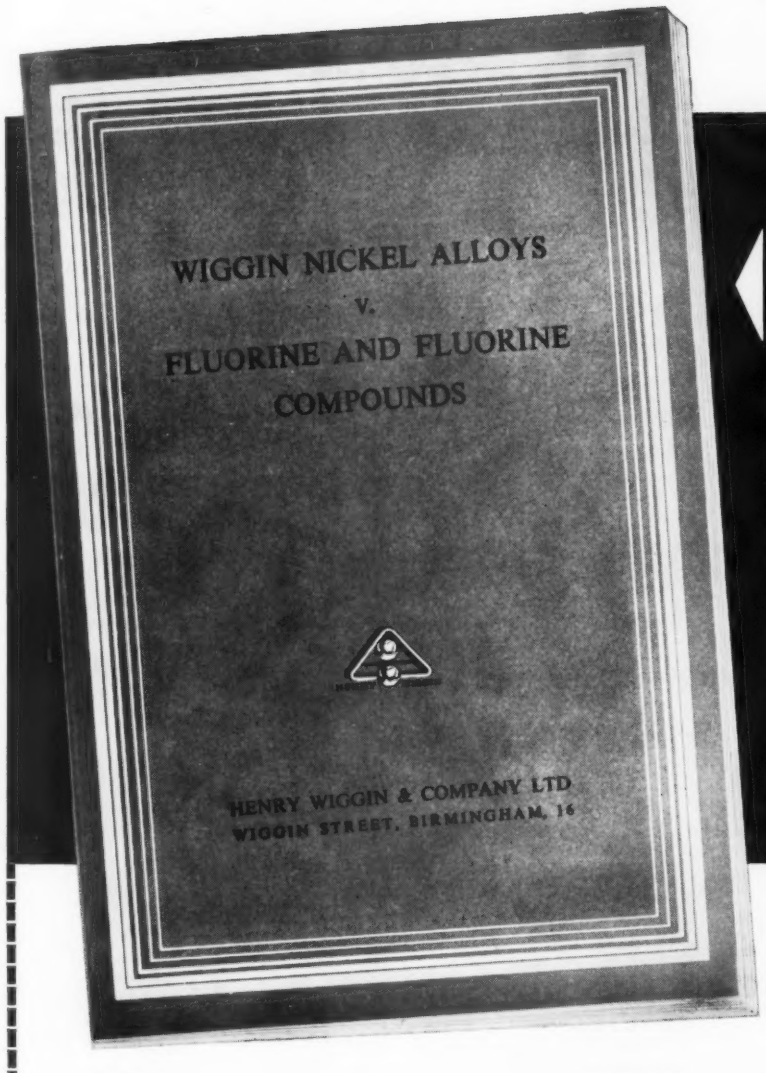

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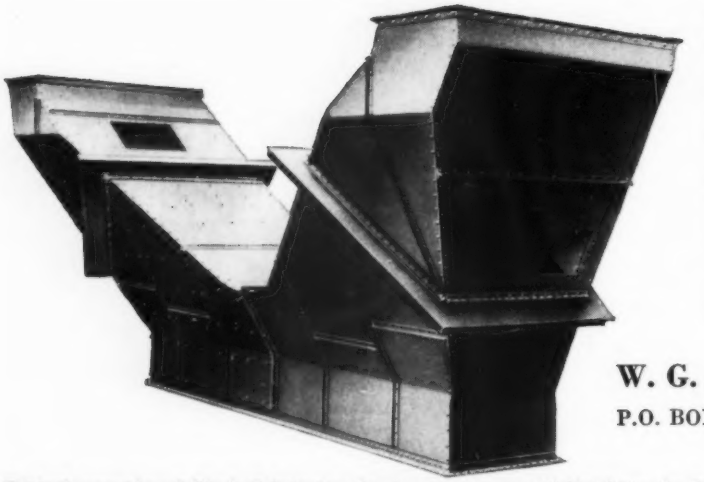

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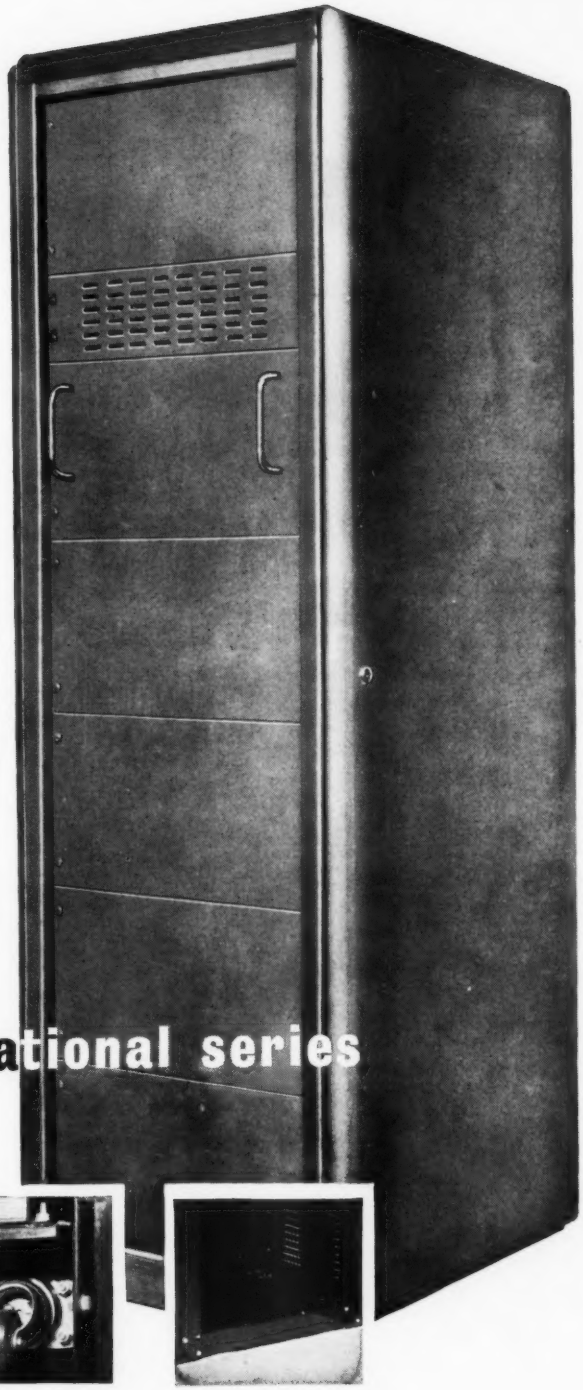

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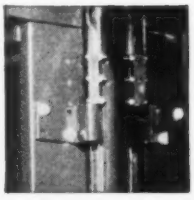

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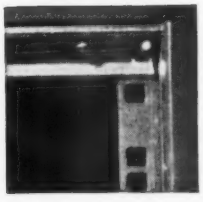

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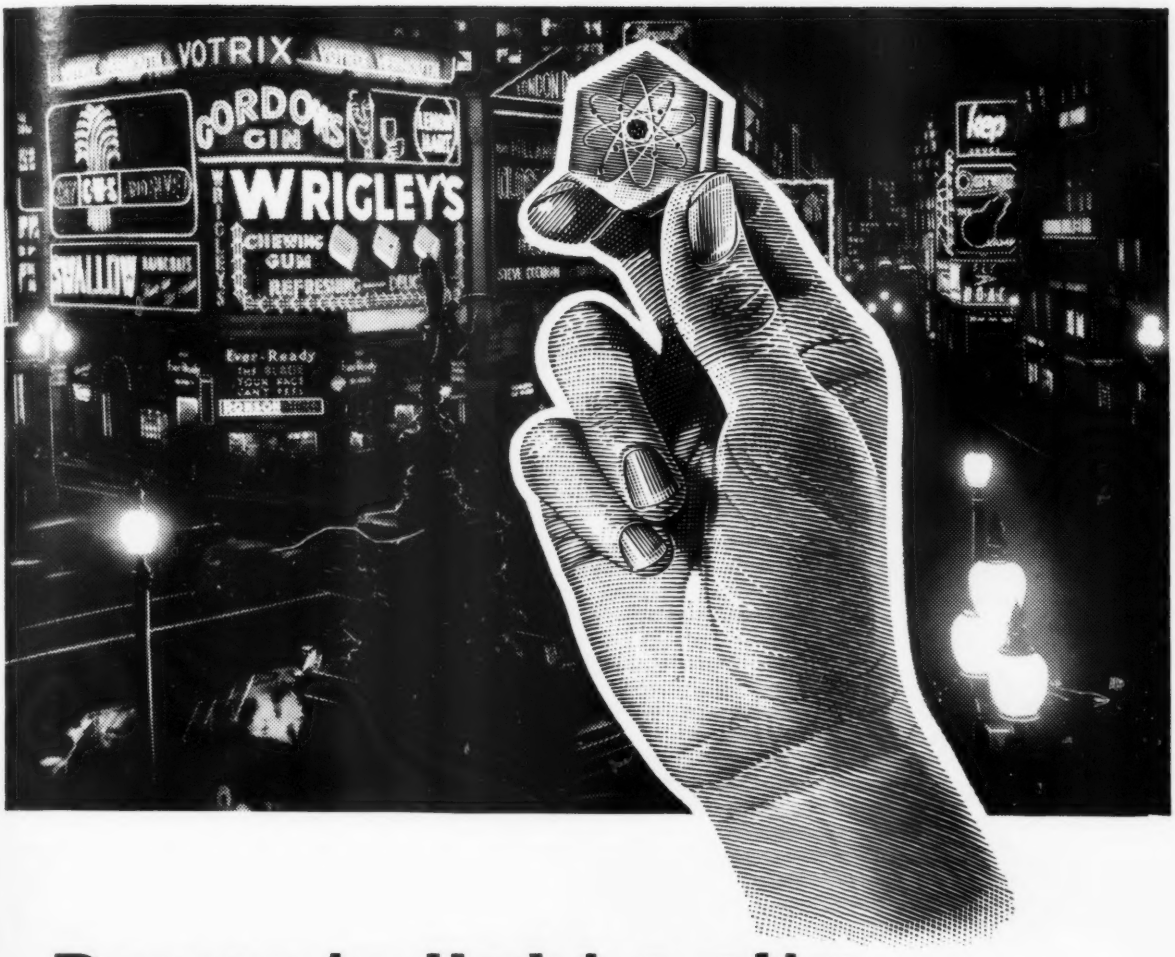

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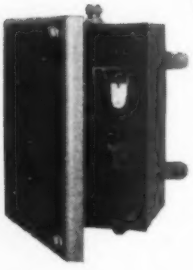

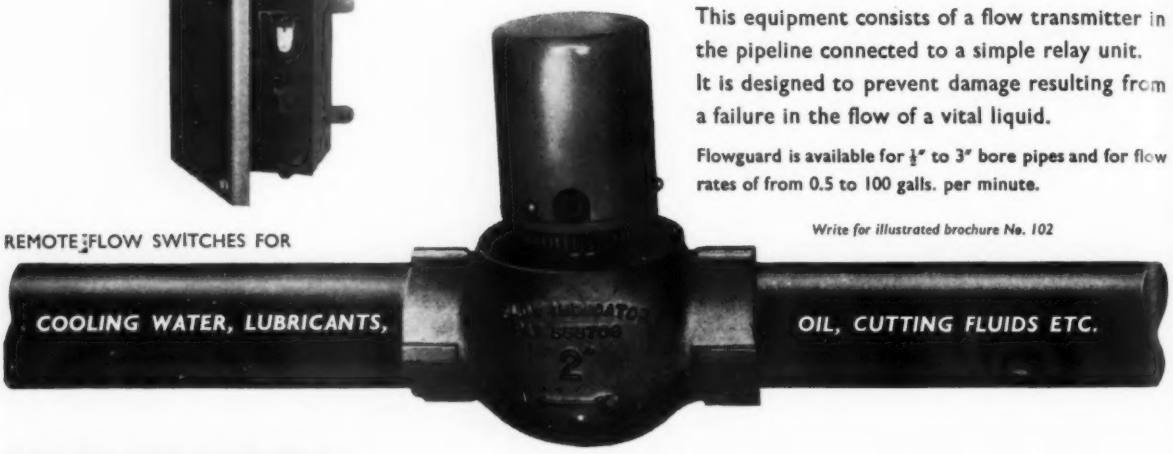

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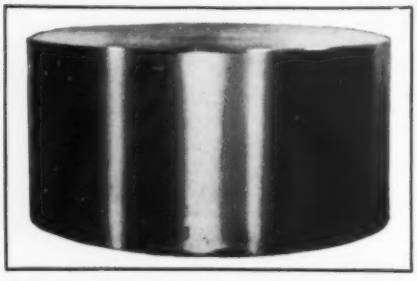

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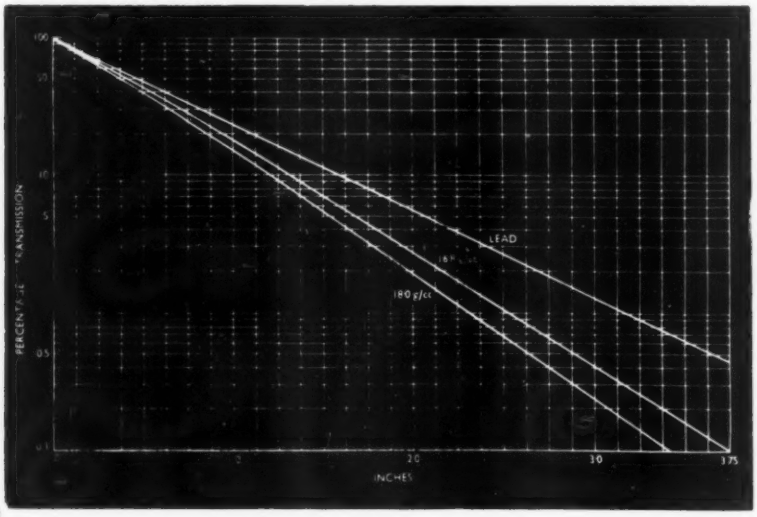

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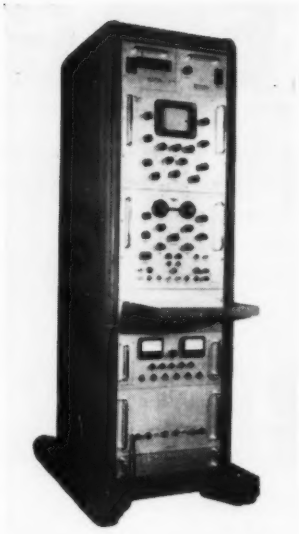

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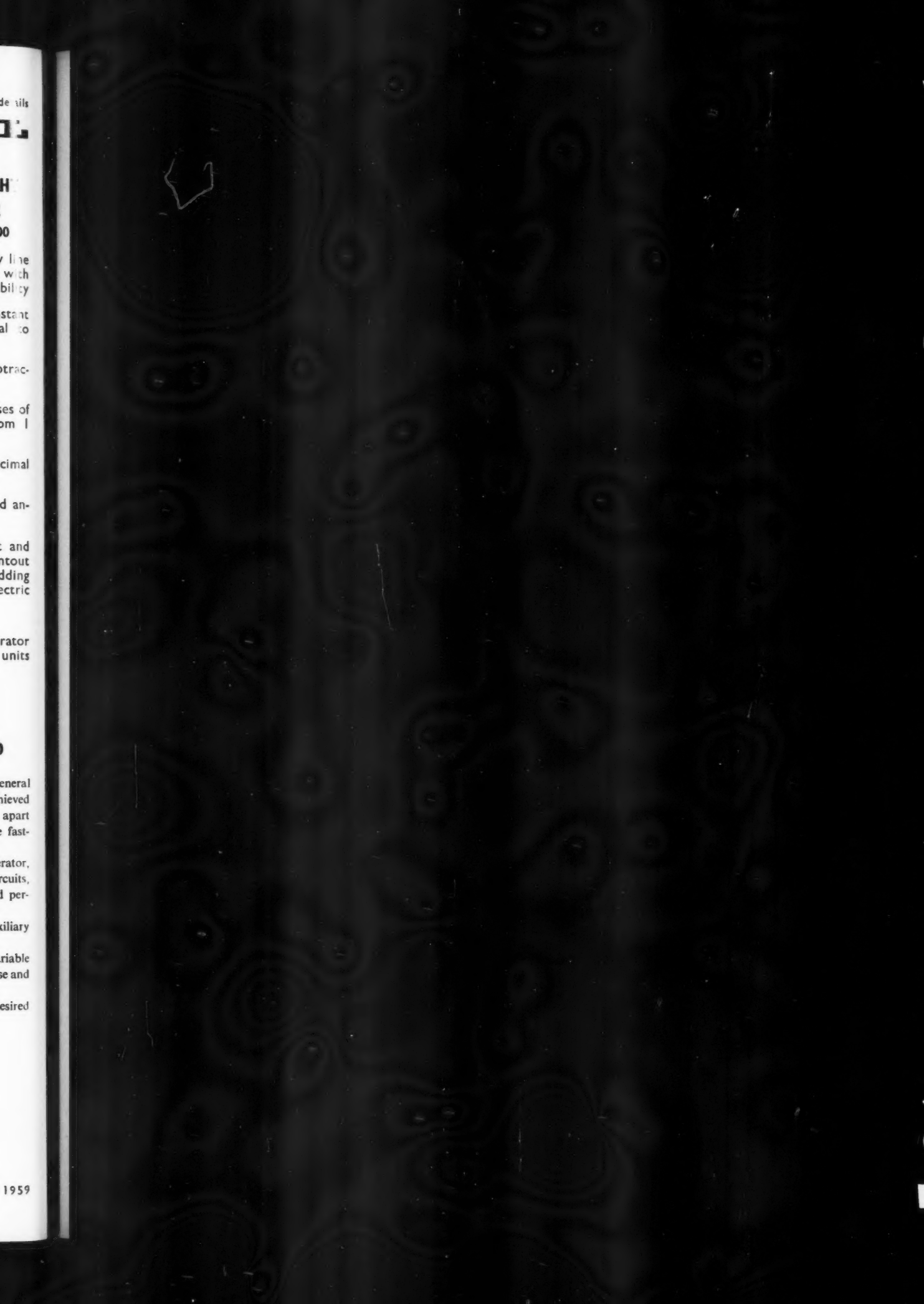

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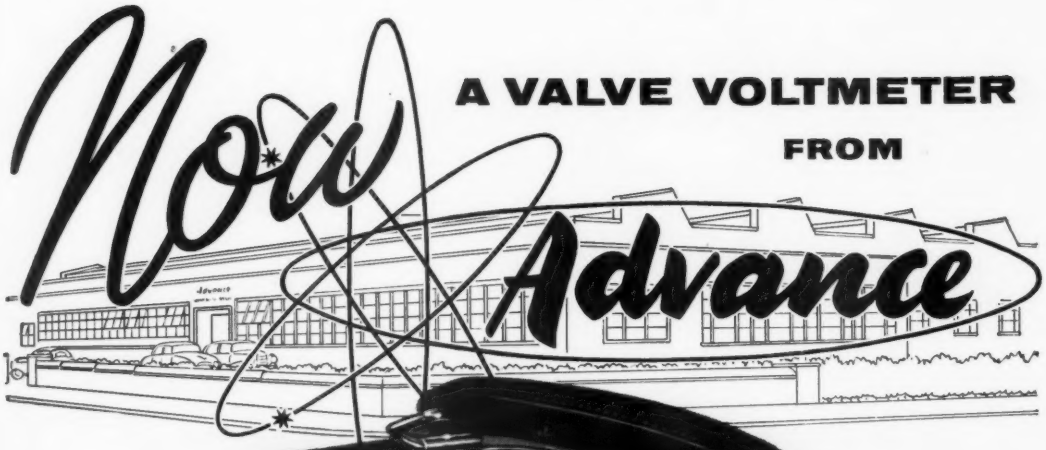

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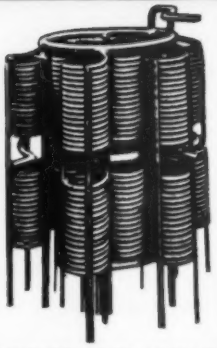

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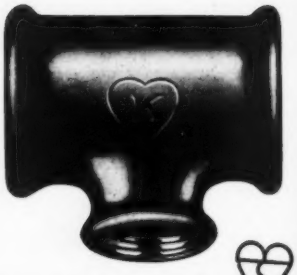

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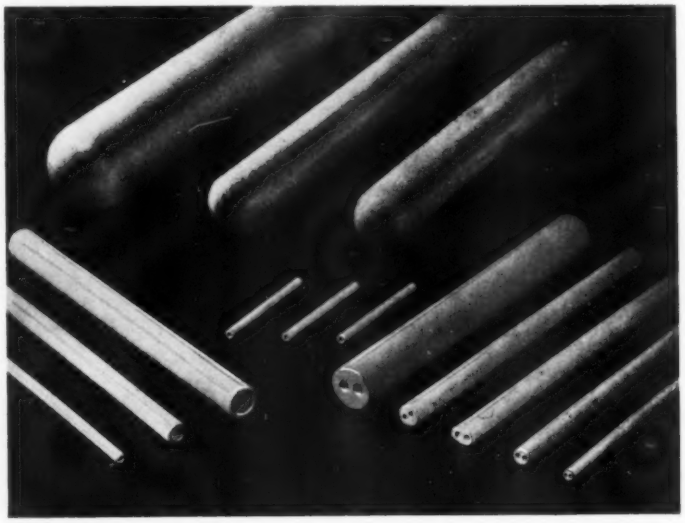

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So simple!

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the foolproof
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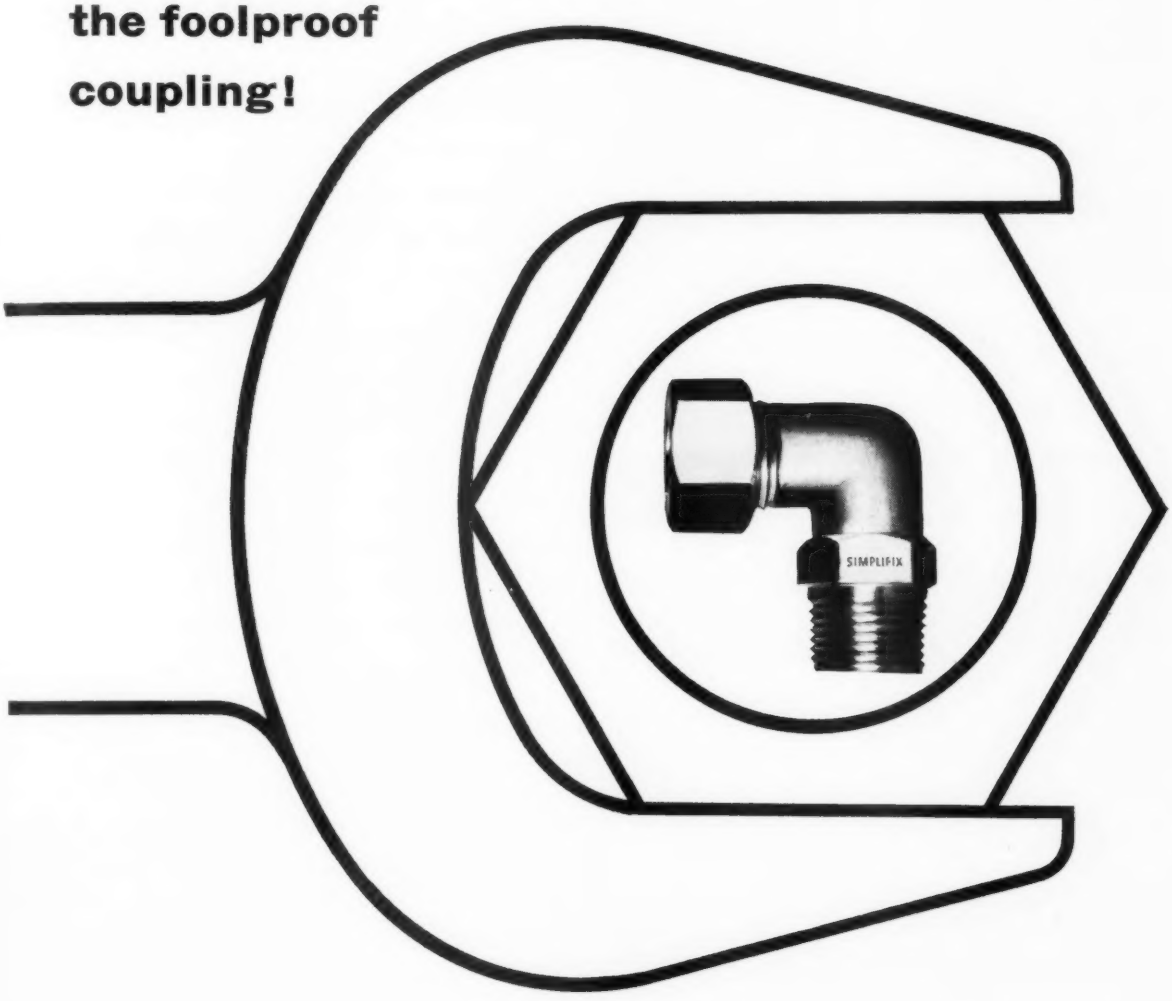

Simplifix couplings form a perfect joint on almost
any kind of tubing including those with very thin walls.
All that is required is tightening with a spanner—
no special work is required on the tube and the anti-friction
washer prevents the tube twisting when the nut is tightened.
Simplifix couplings are suitable for all pipe line systems
up to 2" o.d. In a wide range of interchangeable standard fittings.
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Write for further information and fully illustrated catalogue.

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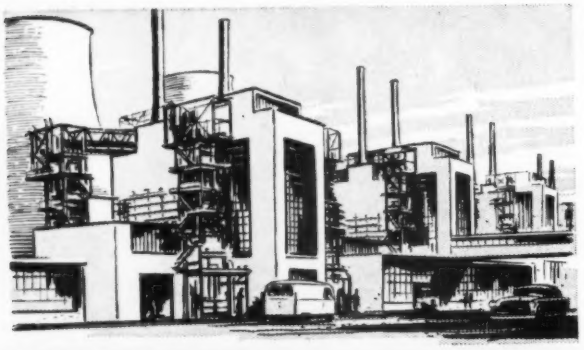

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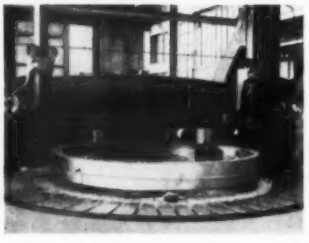

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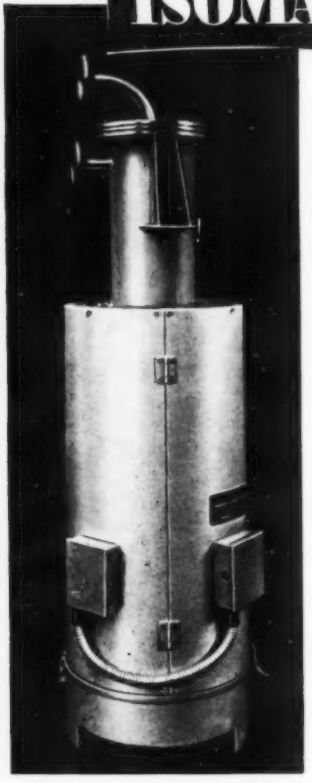

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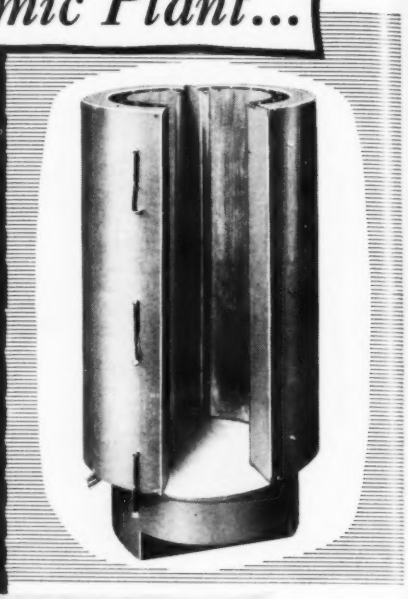

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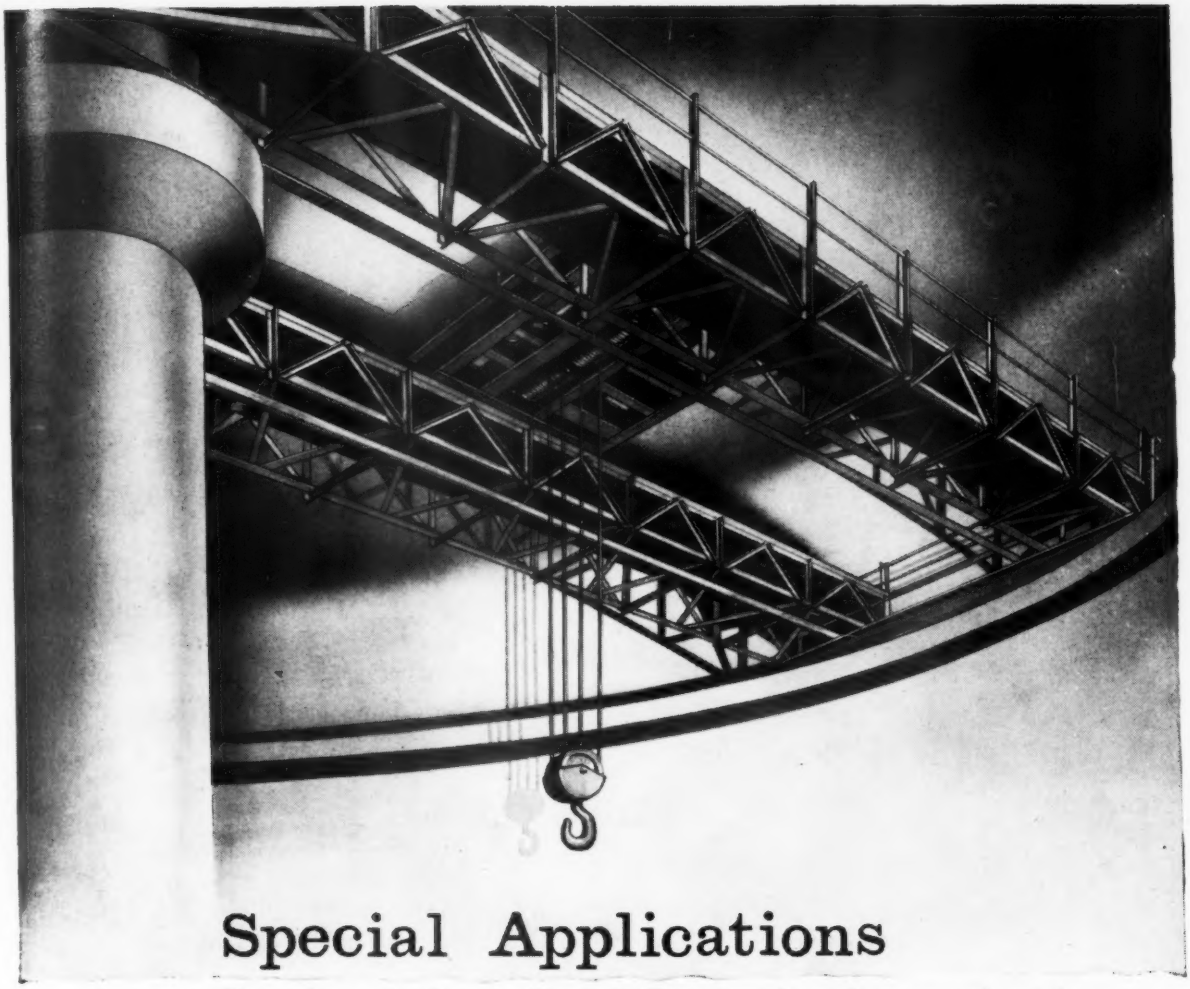

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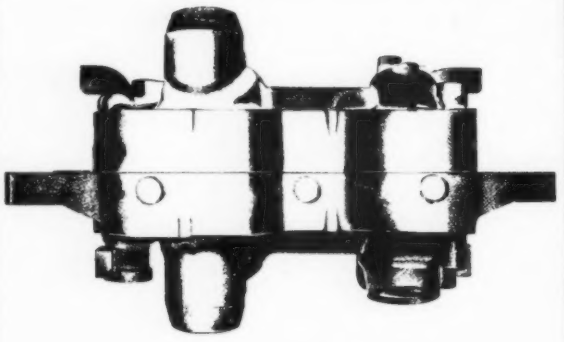

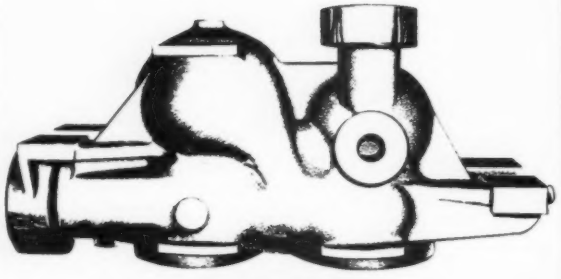

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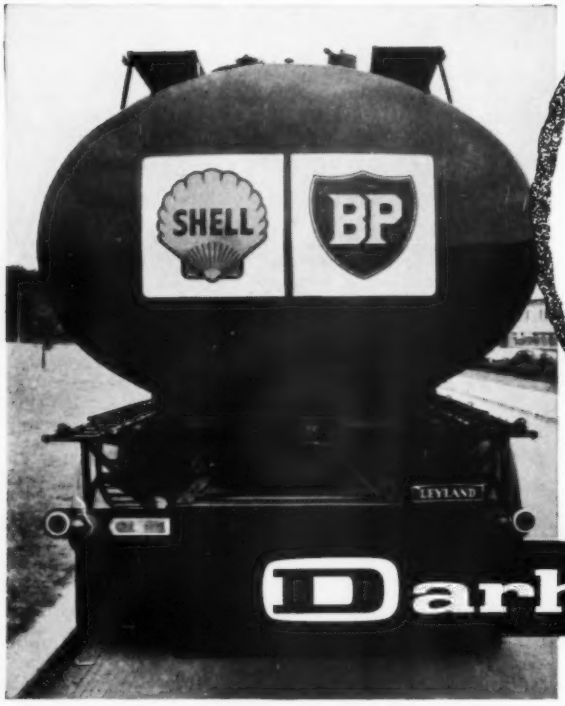
With an end in view...



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Darham are known for the dependability in constructing tanks for the transporting or storage of liquids and powders. Much of the success of a Darham tank can be attributed to the Technical Advisory Service of Designers and Engineers, who study every individual requirement.

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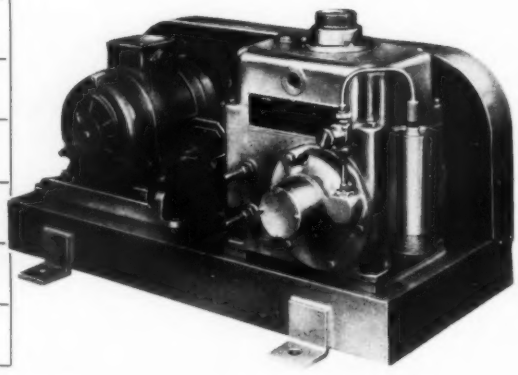
ISC30	0.01	1	32
ISC50	0.005	0.5	48
ISC150	0.005	0.5	144
ISC450	0.005	0.3	450
ISC900	0.01	0.5	900
ISC1500	0.01	0.5	1415
ISC3000	0.01	0.5	2830

* torr = mm Hg (B.S.2751-1958)



"Speedivac" pumps are quiet, high speed machines, protected against contamination by gas ballast operation and the use of specially developed inhibited oils. They include both single and two-stage models and range in size from small bench pumps for the laboratory to large capacity industrial models displacing many hundreds of cubic feet per minute. The larger pumps are fitted with patented and automatic devices to prevent oil suck-back and a range of non-return valves and magnetically operated valves are available for the smaller models.

The table shows SINGLE-STAGE models only but TWO-STAGE models are also available in every size.

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Lagonda tube cleaners are designed to remove all types of deposits from all types of tubes. The scraper head will clear tubes as small as $\frac{1}{2}$" and upwards . . . drills from $\frac{7}{8}$" up will break down the toughest deposit. Expanding brushes, and sectional brushes will leave tubes from $\frac{3}{4}$" up as clean as new. And for even smaller tubes, there is a wide assortment of drills and brushes.

The illustration below is only a partial listing of Lagonda equipment, but enough to indicate that the scope of the Lagonda range covers just about any tube you may need cleaned. If you have a tough tube cleaning job, write for the Lagonda Catalogue No. **Y-48.**

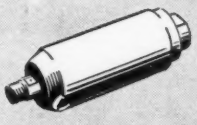
Scraper head

Drill, for hard deposits

Expanding brush.

Small drills, for use with suspension cleaners

1300 Series motor


1100 Series motor

Lagonda TUBE CLEANERS

made by **Consolidated Pneumatic**

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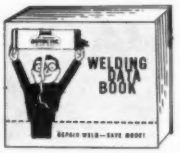

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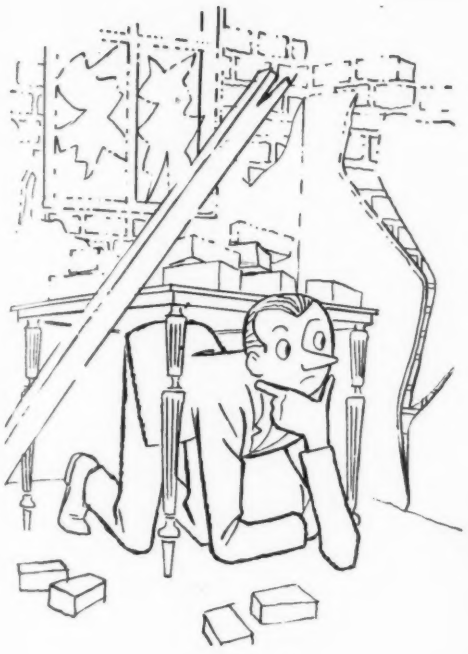

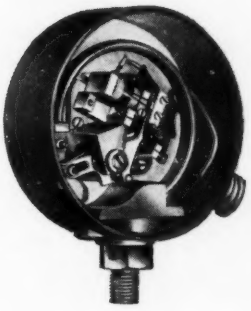

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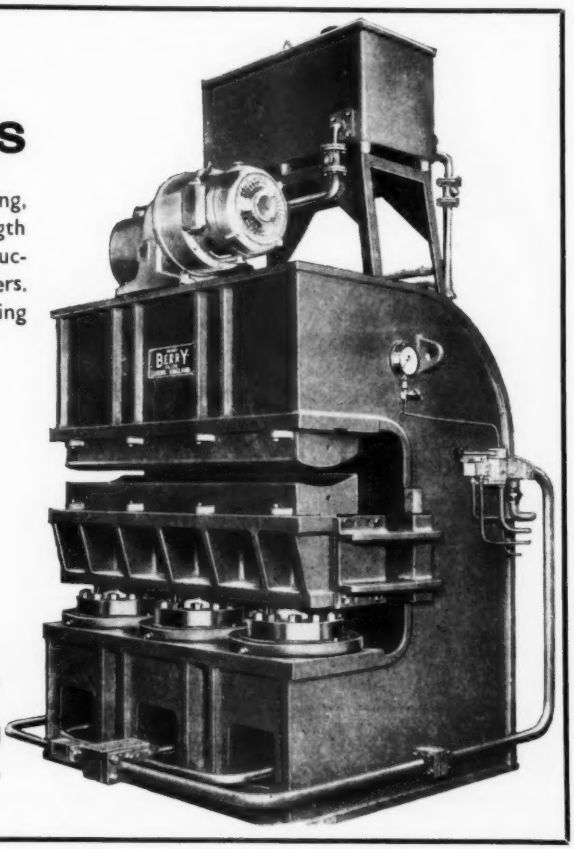

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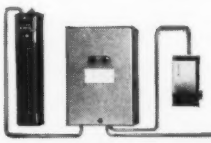

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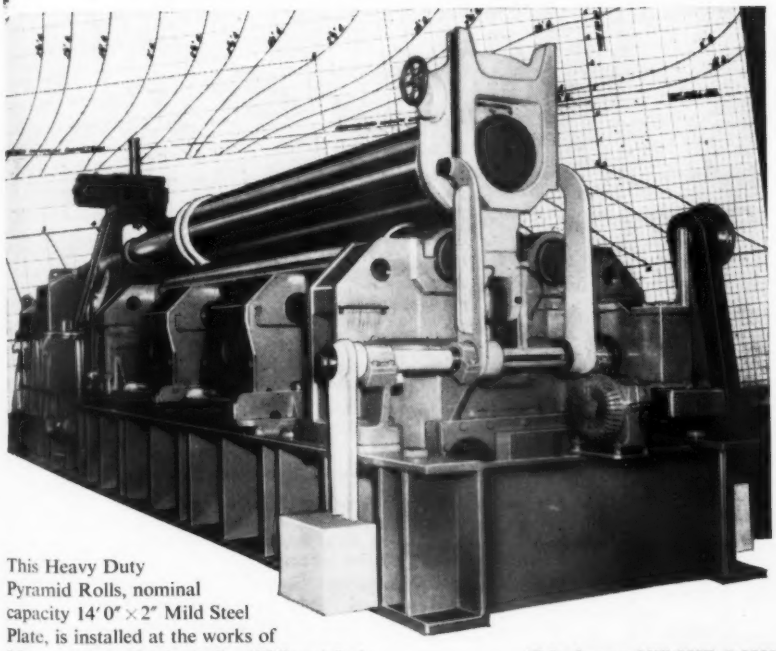

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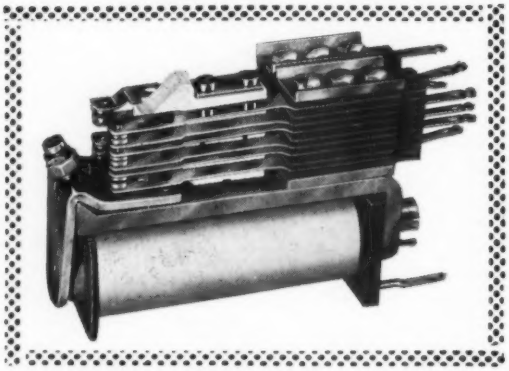

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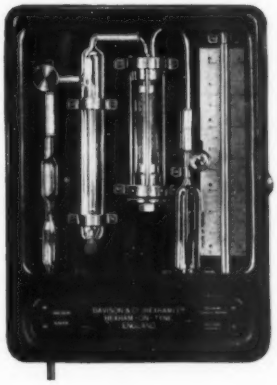

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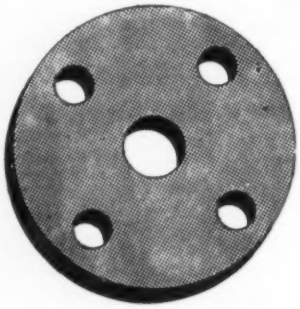

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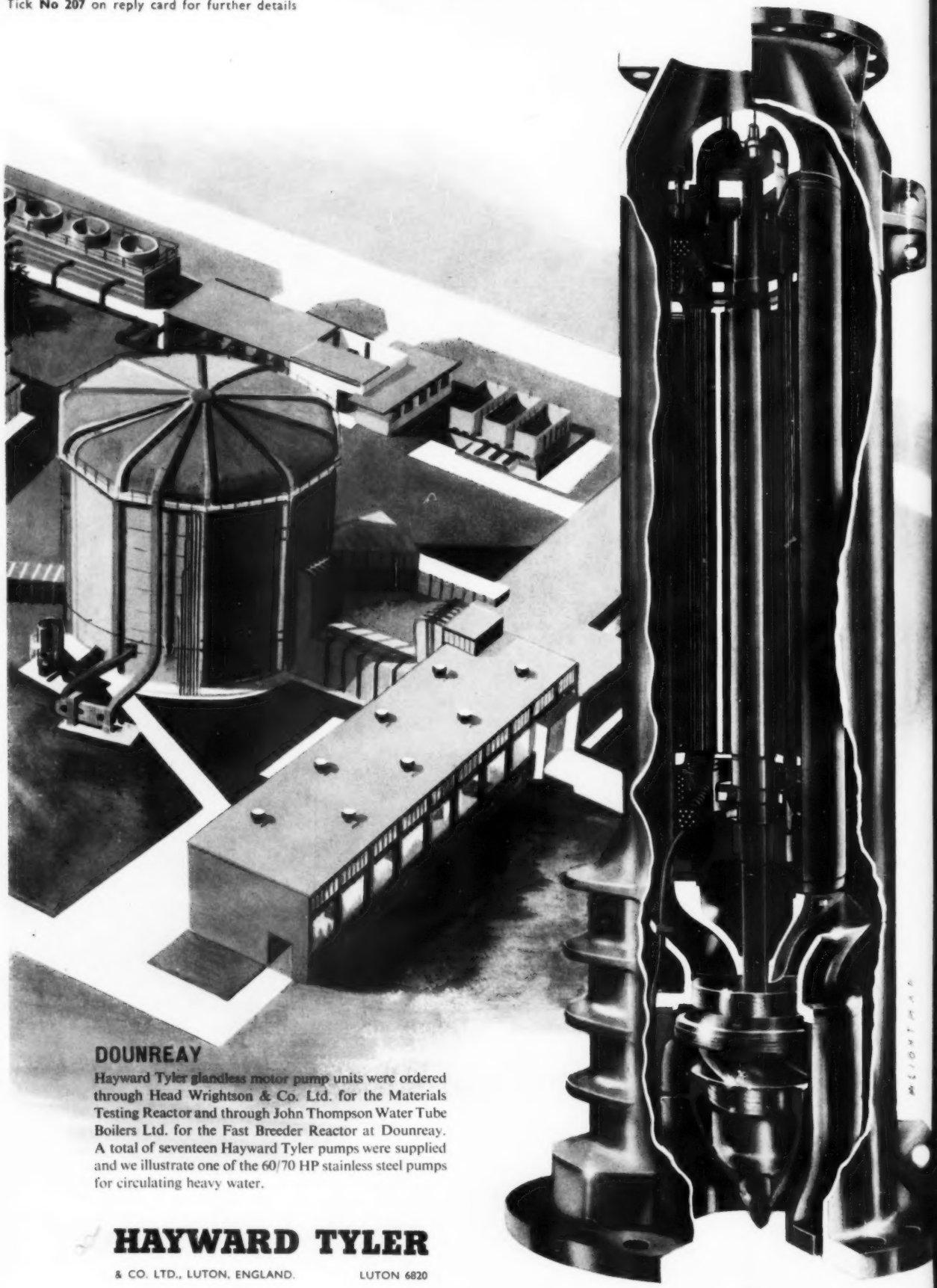

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